

CONSUMER ADOPTION OF FUEL CELL VEHICLES: LESSONS FROM  
HISTORICAL INNOVATIONS AND EARLY ADOPTERS OF BATTERY ELECTRIC  
VEHICLES

By

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I also confirm that this work has not been submitted to another examination office, neither in content nor in shape.

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Signature (Scott John Hardman)

Date: \_\_\_\_\_

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## ABSTRACT

Fuel cell vehicles (FCVs), are one possible solution to address transportation-related climate change, urban air pollution and fossil fuel resource depletion. To solve these issues they need to displace internal combustion engine vehicles (ICEVs), the aim of this thesis is to understand whether FCVs can achieve this. First case studies of successful historical innovations are explored. Second the consumer adoption of battery electric vehicles (BEVs) is studied in detail by using questionnaire surveys and in-depth interviews. Finally, consumer attitudes and perceptions towards FCVs are investigated by conducting in-depth interviews and a FCV trial. From all of these results this thesis finds that FCVs have fewer benefits as perceived by consumers compared to BEVs and ICEVs. This means that consumers may preferentially adopt BEVs and will not be attracted to FCVs. This thesis makes recommendations on how to improve the attributes of FCVs so that they have more benefits for consumers. These efforts would increase the likelihood of consumers adopting FCVs. However, this thesis suggests that the adoption of FCVs still looks unlikely and that fuel cell (FC) stakeholders should seek to concentrate their efforts towards applications of FCs that have viable market entry potential.

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2. Hardman, S., Shiu, E. & Steinberger-Wilckens, R., 2014. **Changing the fate of fuel cell vehicles: Can Lessons be Learned from Tesla Motors?** *International Journal of Hydrogen Energy*, 40(4), 1625-1638
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## CONFERENCE PROCEEDINGS

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3. CARISMA, Cape Town, South Africa 2014. **Niche Market entry for Hydrogen Fuel Cell Vehicles**
4. Sustainable Transportation Energy Pathways Annual Meeting, California. USA 2015. **An Overview of Tesla Battery Electric Vehicle Adopters**
5. European Fuel Cell Forum, Lucerne, Switzerland 2015. **Fuel Cell Vehicles– Lessons from Tesla Motors**
6. University Transport Studies Group, Bristol, UK 2016. **Motivations for the adoption of high-end BEVs**
7. Transportation Research Board Annual Meeting, Washington D.C, USA 2016. **Exploring the decision to adopt a high-end battery electric vehicle: The role of financial and non-financial motivations**

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## LIST OF ABBREVIATIONS

<b>Abbreviation</b>	<b>Definition</b>
AFV	Alternative Fuel Vehicle
AMPS	Advanced Mobile Phone Systems
BEV	Battery Electric Vehicle
CACCP	California Advanced Clean Car Program
CARB	California Air Resources Board
DECC	Department of Energy and Climate Change (UK)
DMFC	Direct Methanol Fuel Cell
DOE	Department of Energy (US)
EPA	Environmental Protection Agency (US)
FC	Fuel Cell
FCHJU	Fuel Cell and Hydrogen Joint Undertaking (EU)
FCV	Fuel Cell Vehicles
GPRS	General Packet Radio Service
GSM	Groupe Speciale Mobile
GSMA	Groupe Speciale Mobile Association
HEV	Hybrid Electric Vehicle
HOV	High Occupancy Vehicle Lane
ICE	Internal Combustion Engine
ICEV	Internal Combustion Engine Vehicle
IIHS	Insurance Institute for Highway Safety (US)
LCV	Low Carbon Vehicle
LPG	Liquid Petroleum Gas
MFC	Multifunctional Fuel Cell
MSRP	Manufactures Suggested Retail Price
NCAP	New Car Assessment Programme
NEDC	New European Drive Cycle
NHTSA	National Highway Traffic Safety Administration (US)
NMT	Nordic Mobile Telephone
PEFC	Polymer Electrolyte Fuel Cell
PHEV	Plug-in Hybrid Electric Vehicle
RAT	Ram Air Turbine
SOFC	Solid Oxide Fuel Cell
SUV	Sports Utility Vehicle
TACS	Total Access Communication System

# CHAPTER 1

Introduction



# **Chapter 1 Introduction**

## **1.1 Background and context to the research**

The market introduction of fuel cell vehicles (FCVs) and battery electric vehicles (BEVs) is important due to their societal and environmental benefits. Both FCVs and BEVs can contribute to a reduction in CO<sub>2</sub>, NO<sub>x</sub>, volatile organic compound and particulate matter emissions (PM<sub>10</sub>, PM<sub>5</sub> & PM<sub>2.5</sub>) due to them having zero tailpipe emissions. This means that they can contribute towards preventing anthropogenic climate change and issues associated with urban air pollution (Offer et al., 2012; Thomas, 2009a). The vehicles both have the ability to be powered with entirely renewable energy, which can be domestically sourced helping contribute toward energy security. Further to this FCVs can help contribute to grid power balancing as any oversupply of renewable energy, such as solar or wind can be stored as hydrogen with the use of an electrolyser (Kempton et al., 2001), to be later used in a FCV. Both vehicles can also contribute to a reduction of noise pollution due to their quiet drivetrains. And finally both vehicles produce very little heat emissions, in comparison to internal combustion engine vehicles (ICEVs), which means they can reduce the effects of urban heat islands (Li et al., 2015). This myriad of benefits clearly shows the rationale for the market entry of both BEVs and FCVs.

In order for FCVs to have the biggest impact on these issues they need to achieve market entry and begin displacing incumbent ICEVs. This thesis aims at developing an understanding of how FCVs can successfully enter markets and be adopted by consumers. This thesis concentrates on FCVs and not BEVs, this is because BEVs benefit from existing consumer adoption research. This research, although limited in

some areas, has contributed to building up an understanding of that issue. The literature for FCVs is far more limited meaning there is much more uncertainty in understanding their potential for consumer adoption. Before an understanding of FCV market entry can be gained an understanding of how any innovations enter markets is needed. This is done by undertaking historical case studies of new technologies that have achieved market entry in the past. The process of market introduction is not possible without consumers, or organisations, adopting the innovation. In the case of this thesis the adopters are consumers and not organisations. Prior to undertaking this study the literature exploring consumer adoption of FCVs was extremely limited. Therefore it was hoped that BEV consumer adoption literature could be reviewed and this would help build an initial understanding of what the situation might be for FCVs. However the literature exploring consumer adoption of BEVs, although insightful, is also limited and needs more clarification. Therefore this thesis also adds to the literature in this area as well as FCVs. Understanding consumer adoption of BEVs and indeed FCVs is important for a number of reasons. Establishing who the early adopters of new technologies are is important so that target consumers can be identified and the vehicles directed towards them. Understanding why consumers will adopt the vehicles is important so that the benefits of the vehicles can be maximised such that they appeal to as large a number of consumers as possible, and so that the right policies can be introduced to encourage adoption. Understanding future purchase intentions of the first buyers of BEVs is important because the market introduction of any new technology is not just reliant upon initial purchases, but also repeat purchases (Crawford and Benedetto, 2011). This thesis adds to the literature

on all of these areas for BEVs, and these findings are then used to gain insights into how FCVs could achieve the same type of market entry as BEVs have done so far.

Once an understanding of how the BEV is achieving successful market entry, by being adopted by consumers is developed, this thesis moves on to understand consumer attitudes toward FCVs. How FCVs are perceived by consumers is important so that the market potential of FCVs can be understood. Automotive OEMs and policy makers around the world are now promoting FCVs. The US DOE have invested more than US\$1.2 billion into fuel cell and hydrogen technologies (U.S Government Accountability Office, 2008). The European Fuel Cells and Hydrogen Joint Undertaking (FCHJU) is investing €1.33 billion (US\$1.44 billion) into research and development activities between 2014-2020 (Fuel Cells and Hydrogen Joint Undertaking, 2015). According to reports Toyota has released US\$4.2 billion in common equity and shares for sale so that they can fund their FCV program (Bloomberg, 2015; Hybrid Cars, 2015). As of 2013 Daimler had invested over €1 billion (US\$1.08 billion) into their fuel cell program (Daimler, 2013). For context it is typical for an OEM to spend in the region of US\$1-6 billion when developing an entirely new ICEV model, so these figures are not out of line with existing expenditures. But these investments into new ICEVs achieve a return thanks to high volume sales of the vehicles. The investments into FCVs along with investments from other OEMs and governments are extremely high risk if the market potential and likelihood of consumer adoption is not fully understood. And indeed poorly planned market entries have led to failures in the past (Rogers, 2003). It is not yet known how consumers perceive FCVs due to the lack of literature; therefore it is severely needed in order to reduce risk and uncertainty.



## **1.2 Research Question, Aim and Objectives**

The research question that this thesis aims to answer is; will FCVs be adopted by consumers and achieve market entry? A number of OEMs are currently developing and bringing to market commercial FCVs and their expectation is that these vehicles will be adopted by consumers. At present though there is very little evidence to suggest that consumer will or will not be willing to adopt FCVs. This thesis works towards building an understanding of this issue to answer the research question of that is the subject of this thesis. In order to answer this question an understanding of how new technologies enter markets is needed along with what causes consumers to adopt an innovation. This is gained through the use of historical case studies of successful historical innovations. Then by conducting questionnaires and interviews with consumers who have made the decision to adopt a BEV. This helps to understand how innovations enter markets, and how the BEV is entering markets at present. By gaining this understanding it is possible to understand the conditions that will need to be present in order for FCVs to be successful. Once this is achieved the compatibility of FCVs, with what is needed in order for them to entry markets, can be assessed. This knowledge is gained by asking consumers who are typical early adopters of automotive innovations questions about FCVs. By ascertaining this information, it will be possible to understand whether consumers will choose to purchase FCVs rather than ICEVs or BEVs, thereby finally answering the research question of this thesis.

The aim of this thesis is ultimately to build an understanding of how FCVs can achieve market entry by being adopted by consumers. The hope is that

recommendations can be made towards increasing the likelihood of successful introduction of FCVs. In order to reach this aim a number of objectives first need to be met. The first of these is developing an understanding of innovations that have historically achieved market entry success. Then by examining how BEVs are achieving successful consumer adoption at present. Once the former two objectives have been accomplished the final objective is to understand consumer attitudes toward FCVs.

The aim of this thesis is to develop an understanding how fuel cell vehicles can achieve market entry success. The objectives are in detail:

1. Examine how innovations have historically achieved market entry success
2. Examine how battery electric vehicles are achieving market entry success at present by;
  - 2.1. Understanding who is adopting battery electric vehicles
  - 2.2. Understanding motivations for adopting a battery electric vehicle
  - 2.3. Understanding the benefits of owning a battery electric vehicle
  - 2.4. Understanding future purchase intentions of battery electric vehicle adopters
3. Examine the potential of fuel cell vehicles to be adopted by consumers by;
  - 3.1. Understanding consumer attitudes toward fuel cell vehicles
  - 3.2. Understanding barriers to consumer adoption of fuel cell vehicles

### **1.3 Thesis Overview**

This thesis brings together diverse assemblage of research which reflects the interdisciplinary nature of the project. The results in this thesis come about thanks to

three different methods these being historical case studies, the use of questionnaire surveys, one online that gathered 340 responses and a smaller verbally administered survey with 30 responses. Further to this this thesis contains the findings from 39 in-depth interviews with early adopters of BEVs.

The 2<sup>nd</sup> and 3<sup>rd</sup> chapters in this thesis present two different reviews of academic literature. The first of these, chapter 2, reviews theoretical literature. This includes disruptive innovation theory, diffusion of innovation theory and the theory of consumption values. The second literature review, chapter 3, reviews consumer adoption research specifically in the automotive sector. It therefore concentrates on literature investigating consumer adoption of Hybrid Electric Vehicles (HEVs), Plug-in Hybrid Electric Vehicles (PHEVs), BEVs and FCVs.

Chapter 4 of this thesis describes the three different methods used in this study.

The 8 results chapters (Chapter 5-12) of this thesis are split into three parts. The first part, which is chapter 5, 6 and 7, explores the market entry of historical innovations using mostly secondary data and this section meets the first objective of this thesis. The second part, chapter 8, 9 and 10, concentrates only on the consumer adoption of BEVs thus meeting the second aim of this thesis. The final part of the result chapters, chapter 11 and 12, look towards understanding consumer attitudes towards FCVs and meet the third and final objective of this chapter.

Chapter 5 is the first results chapter in this thesis, it consists of 7 historical case studies of disruptive innovations. The majority of the innovations studied in this chapter are not related to the automotive sector. They therefore help to build an understanding of how innovations in general enter markets. Chapter 6 uses the same

historical case study methods as the preceding chapter. This chapter concentrates on just one case of market entry, this being the niche high-end market entry of Tesla Motors, a company developing BEVs. Chapter 7 does not study the introduction of an innovation per se rather it studies the introduction of infrastructure that is required for an innovation. This chapter studies the introduction of mobile phone infrastructure, again using a historical case study method.

Chapter 8, 9 and 10 are the first chapters that present primary data. These chapters explore consumer adoption of BEVs. Chapter 8 presents data from an online questionnaire survey that was administered in 2014 and yielded 340 respondents all of who have adopted a BEV. This chapter presents socio-economic, psychographic and vehicle attribute opinion data. Chapter 9 uses data from the same online questionnaire survey. This time though the chapter explores what premium consumers have been willing to pay for their BEV compared to an ICEV, also known as their willingness to pay for a BEV. Chapter 10 presents qualitative data from in-depth interviews with 39 high-end BEV adopters. High-end BEV adopters are the only group of BEV adopters in this chapter and they were chosen as the target of this chapter due to the findings from chapter 8 and 9. They were chose because it was believed that this group would be most similar to the early adopters of FCVs. This was due to them having high levels of educations, high incomes, favourable attitudes to change, amongst other attributes. They have also purchased an expensive vehicle, a shared trait between Tesla BEVs and FCVs.

Chapter 11 and 12 finally consider consumer responses to FCVs. The in-depth interviews with high-end BEV early adopters were divided into two parts, the first half explored BEVs. The second part of the interviews concentrated on these adopters'

attitudes toward FCVs and this is the topic of chapter 11. The final results chapter in this thesis explores consumer attitudes to FCVs. This chapter (Chapter 12) gathers data from consumers who have actually driven both a FCV and a BEV. A small sample of 30 people was gathered, and these people's perceptions of FCVs were surveyed.

### **1.3.1 Summary**

Due to the unique data that has been gathered this thesis has been able to make a number of important contributions to the literature. The case studies themselves bring about new findings allowing stakeholders of new technologies to better understand their market entry potential. Furthermore a criterion is put forward that allows the easy identification of whether a new technology is a disruptive technology. The case study of infrastructure development allows stakeholders to understand how new infrastructure can be developed in order to support the market introduction of technologies that are reliant on that infrastructure. The most significant and novel contributions in this thesis come from the primary research. First, at the time of completing the questionnaire survey, the sample of 340 early adopters of BEVs was unique within the literature with no other studies gathering empirical evidence from this number of early adopters. The results gathered in that questionnaire survey are original, with no other studies exploring the same topics, and no other studies being able to make a distinction between the two different types of BEV adopters. This data is unique in exploring the socio-economic and psychographic profiles of early adopters, along with the benefits of owning a BEV. The data records the future purchase intentions of BEV adopters, something not seen in any other studies. It

finally explores what price premium early adopters have been willing to pay for a BEV in comparison to ICEVs, using empirical evidence from early adopters. This is again something that was previously missing within the literature. The study involving 39 in-depth interviews is the only one in the literature that gathers such in-depth information from BEV early adopters. This sample can be used to corroborate the findings of the questionnaire survey, but it also brings new findings relating to the reasons for purchasing a BEV and it also discovers new benefits of BEV ownership. This reason for purchase and benefits of ownership data is the first of its kind. Some of the questionnaire survey and interview results are compared to results of unpublished data from academics at UC Davis, this increases the robustness of these findings. These comparisons are discussed in more detail throughout the thesis. The 39 BEV adopters were also asked questions about FCVs. The results from this investigation are unique as it is the first study to assess attitudes of genuine early adopters toward FCVs. Finally, the sample of 30 participants in a FCV trial, although small, is an original contribution to the literature, being the first study in the UK and Europe to survey people with driving experience of a FCV, and only the second study globally. Respondents in this study are also able to provide information about both BEVs and FCVs, having experienced each vehicle types. This is something no other study has been able to do prior to this and allows comparisons between ICEVs, BEVs and FCVs. Both of these studies on FCVs find that consumers do not perceive FCVs as having significant benefits compared to ICEVs and BEVs, something that will have a negative effect on rates of adoption. The fact that this thesis gathers a diverse body of data all of which are unique within the literature

means that it can offer an unprecedented understanding of consumer adoption of BEVs and FCVs.

# CHAPTER 2

Literature review- Theoretical background



## **Chapter 2 Literature Review- Theoretical background**

### **2.1 Introduction**

This chapter reviews a number of theories that are relevant for this thesis. The first is Disruptive Innovation theory (Christensen, 2013a) which explains technologies that are remarkably different from incumbents, something which a FCV is when compared to ICEVs. High-end encroachment is a theory that explains the market entry of innovations that possess new attributes and improved performance over incumbents. High-end encroachment also helps understand how innovations that are more expensive than incumbents may enter markets, hence its relevance for FCVs. High-end encroachment was not included in Clayton Christensen's original disruptive innovation theory, however, subsequent research suggests that it should be included in the definition meaning both high-end and low-end encroachment are examples of disruptive market entry (Schmidt, 2004; van der Rhee et al., 2012; Van Orden et al., 2011).

Although disruptive innovation and high-end encroachment are useful for their explanations of market entry they have shortcomings. They do not identify what types of people are the first people to adopt innovations. Secondly they do not identify exactly what attributes an innovation should have in order for it to be purchased by consumers. Therefore diffusion of innovations or Rogers' theory is reviewed (Rogers, 2003). Rogers' theory is used because it makes generalisations about what types of people will be the first to adopt an innovation, and it also outlines what attributes an innovation should have in order for it to be adopted. The attributes outlined in Rogers'

theory are: relative advantage, compatibility, complexity, trialability and observability. The most important of these is relative advantage, and if an innovation has significant levels of relative advantage it will have higher rates of adoption and increased likelihood of market entry success.

Rogers' theory is the most popular theory that explains how innovations enter markets. However, its explanation of relative advantage is weak. Precisely how relative advantage will materialise within an innovation is not clear based on the theory. Therefore one final set of theoretical literature is added which is on consumer perceived value. This literature breaks down more clearly what the benefits of a technology will be to consumers. Therefore this literature is used to understand how relative advantage might emerge in an innovation, and indeed FCVs.

## **2.2 Disruptive Innovation**

Many emergent technologies, especially those that are markedly different from existing technologies, are potentially beneficial to society but struggle to establish themselves and compete successfully with the incumbent technologies. Initially it was thought that disruptive innovation theory (Bower and Christensen, 1995) could be used to increase the understanding of disruptive technologies, and hence FCVs. However, models lack the complexity of real-world socio-technical transitions, and the definition of disruptive innovation is not clear based on the existing literature as is explained below. An improved way of determining when an innovation is a disruptive innovation is put forward later on in this thesis.

'Disruptive Innovation' is a term widely used within the literature; Clayton Christensen originally introduced the term. Disruptive innovation is defined by Christensen as 'a

*process by which a product or service takes root initially in simple applications at the bottom of a market and then relentlessly moves up market, eventually displacing established competitors'* (Bower and Christensen, 1995). Disruptive technology predates the term disruptive innovation. Christensen changed the term to disruptive innovation so that it would include services as well as products. Often within the literature the terms are used interchangeably. Despite the widespread use of both by Christensen and other academics, there is still some ambiguity surrounding the definition of disruptive innovation.

Tellis (Tellis, 2006) argues that Christensen's definition is not measurable and has little predictive value. Christensen's theory states that '*Disruptive technologies displace incumbent technologies*', but that is something that can only be ascertained with hindsight. For both the developers of the technology and existing market leaders it would be more useful to be able to assess in advance to what extent a technology has the potential to become a disruptive technology.

Danneels (Danneels, 2004) raises the question of '*what is a disruptive technology?*' He states that Christensen's original work does not establish clear criteria to determine whether a technology is a disruptive technology. Danneels puts forward his own definition of disruptive technology as '*A disruptive technology is a technology that changes the bases of competition by changing the performance metrics along which firms compete.*' Whilst this definition does add to the literature it does not make it easier to identify when a technology is a disruptive technology.

The most recent addition to the literature of disruptive innovation comes from Gilbert (Gilbert, 2013), who defines a disruptive innovation as '*A new technology that*

*unexpectedly displaces an established one*'. The advantage of Gilbert's definition is that it highlights one particular factor about what makes a technology disruptive: the often unexpected nature of the disruption of established technologies. But it still is missing some key factors and it does not allow the determination of whether a new technology is likely to become a disruptive technology. Again, it only really allows an understanding of whether a technology has been disruptive in hindsight.

## **2.3 High-end Encroachment**

High-end encroachment is not a new market entry strategy for automotive technologies. Daimler, for example, has often introduced new automotive technologies in their flagship S-Class vehicle. Many of these innovations are expensive but the high price of that vehicle allows costs to be absorbed. More recently carbon fibre body panels and ceramic brakes have been introduced first in high value sports cars. These technologies are then diffused down to lower value vehicles as costs are reduced. In addition to these automotive technologies many other disruptive innovations have entered markets via high-end encroachment including: Quartz Watches, Hydraulic Excavators, MP3 Players and Steamships to mention just a few (Hardman et al., 2013).

Christensen did not include high-end encroachment in the original definition of disruptive innovation (Christensen, 2013b). However much subsequent literature (Hardman et al., 2013; Schmidt, 2004; van der Rhee et al., 2012; Van Orden et al., 2011) presents a good case for including high-end encroachment into the theory. Additionally, the mobile phone, which is an example of high-end encroachment, is classified as a disruptive innovation by Christensen (Christensen, 2013a; Yu and

Hang, 2010). The effects of high-end encroachment on the market can be immediate and significant, meaning that innovations that enter markets via high-end encroachment can be disruptive (Schmidt and Druehl, 2008).

There are three types of high-end encroachment; New Market, New Attribute and Immediate High-End Encroachment. The type of high-end encroachment depends upon the level of core attribute and ancillary attribute performance changes compared to the incumbent innovation (Van Orden et al., 2011), as shown in Figure 2.1. The first customers who purchase high end innovations are typically innovators, as based on Rogers (Rogers, 2003) theory (see below). These innovators typically place a higher value on the performance advancements of the high-end innovations, more than low end customers would (Schmidt and Druehl, 2009).

New market encroachment depends upon the highest level of core attribute improvements along with strong ancillary attribute improvements. The innovations will also be high priced; they will open up new markets at the high priced end of a market (Schmidt, 2004; van der Rhee et al., 2012). This is usually the first stage of a market entry strategy and the innovations will generally diffuse down from this high-end market to progressively lower markets as cost reductions are achieved.

New attribute high-end encroachment is where core attributes are improved to a similar extent as new market encroachment. With this strategy ancillary attributes are only moderately improved compared to incumbent technologies. These innovations have higher costs than incumbent technologies, but the difference in cost is less significant than with new market innovations. These innovations enter the top of

existing markets, they do not open new markets, the innovations then diffuse to lower market levels (van der Rhee et al., 2012). Innovations in the automotive sector that fit this pattern include hybrid vehicles where ancillary attributes are moderately improved but core attributes are often much improved over comparable ICE vehicles.

It should be acknowledged that for disruptive innovations high-end encroachment is not the only appropriate market entry strategy. Low-end encroachment where technologies enter at the bottom of the market in low value applications is also possible (Christensen and Yang, 2010). Low-end encroachment is not being explored for FCVs because this market entry strategy would not be possible due to initially high purchase prices. The high prices inherent with FCVs mean they would not be able to compete with incumbent ICE vehicles on price, at least in the early stages of the market. According to (Van Orden et al., 2011) there are 6 types of encroachment patterns, 3 high-end and 3 low-end encroachment patterns, as shown in Figure 2.1.

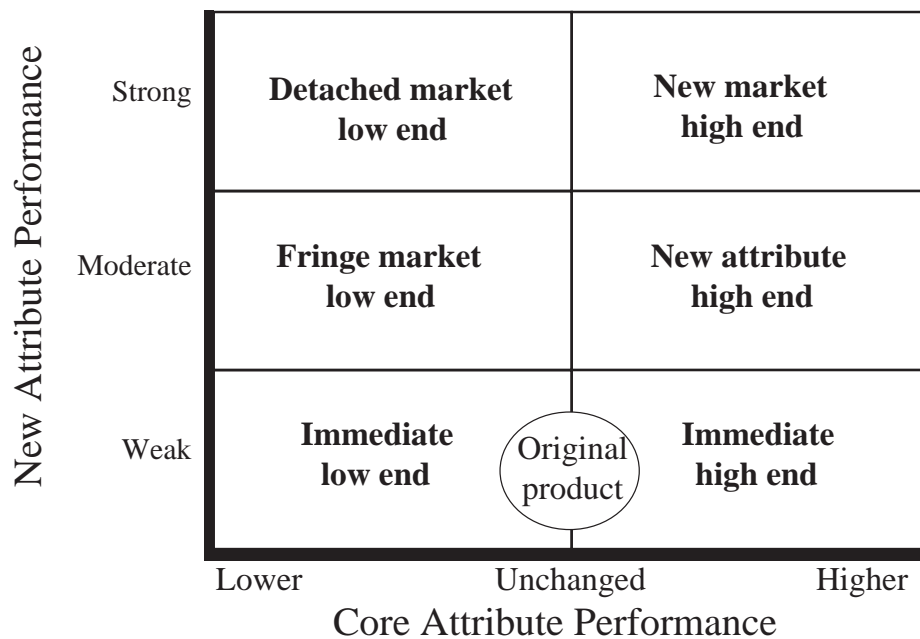


Figure 2.1: The 6 types of encroachment patterns from (Van Orden et al., 2011).

## 2.4 Diffusion of Innovations

Diffusion of Innovations (Rogers, 2003) was constructed based on ground breaking primary research meaning the theory already had strong evidence for it being highly relevant. Primary diffusion research began in the 1940s and 1950s and the book “Diffusion of Innovations” was first published in 1962, meaning it has withstood 54 years of critique. Thanks to the theory having relevance to many areas, a large body of empirical evidence supporting the theory has been collected. The growth in diffusion research has meant that this body of empirical evidence has grown to a considerable size. This has allowed the creation of coherent generalisations on the diffusion of innovations.

It would be impossible to outline all aspects of the theory, therefore the aspects of the theory that are useful for this thesis are reviewed here. Rogers’ theory has 4 main

components. These are the innovation itself, the communication channels, time and the social system that is adopting it. All of these have an impact on the rate of market uptake. This thesis is concerned with the innovation itself and the social system. Understanding the innovation itself is important so that its potential for market entry success can be understood. Understanding the social system is important so that an understanding of who will adopt the innovation can be gained. This aspect of diffusion research is usually focused on identifying who the early adopters of a new technology would be. These 2 components of Rogers theory are outlined below.

According to Rogers an innovation is defined as:

*“An idea practice, or object that is perceived as new by an individual or other unit of adoption. It matters little, so far as human behaviour is concerned, whether or not the idea is objectively new as measured by the lapse of time since its first use or discover. The perceived newness of the idea for the individual determines his or her reaction to it. If an idea seems new to an individual to the individual it is an innovation.”* Chapter 1, Page 12 (Rogers, 2003)

From historical case study research on the diffusion of innovations Rogers (Rogers, 2003) observed 5 attributes of innovations that are directly related to rates of adoption. An innovation that possesses these attributes will achieve faster rates of adoption than technologies that do not possess these qualities. Rogers presents case studies of innovations that have these attributes and how they diffused through the market as a result. He also shows a limited number of case studies where innovations fail to diffuse due to lack of some of these qualities. The attributes are perceived attributes meaning that the innovations only need to be perceived by



potential adopters as superior to the incumbent in order to be successful. This means that innovations that may be objectively superior to incumbents can actually be perceived as inferior and vice versa. Below Rogers' 5 attributes of innovations are summarised along with supporting literature.

### **2.4.1 Relative Advantage**

Relative advantage is the degree to which an innovation is perceived as being superior to a technology that it supersedes. This can be measured in a number of ways including economic terms, social issues, convenience, satisfaction and the physical attributes of an innovation. Relative advantage has been found to be one of the strongest predictors of rates of adoption for innovations. It is therefore believed to be one of the most important factors in the diffusion of innovations (Rogers, 2003).

Brockman & Morgan suggest that efficiency, economic cost, return on investment and social characteristics effect relative advantage (Brockman and Morgan, 1995). Cost is often considered to be one of the most significant contributors to relative advantage. Low cost innovations can therefore gain immediate relative advantage by being cheaper than incumbents. High costs can reduce relative advantage, as it will affect the cost benefit ratio. This does not mean that expensive innovations cannot achieve market entry, but means that high cost innovations must have additional benefits that justify their price. In historical studies it has been observed that innovations with greater relative advantage will diffuse more rapidly than innovations without this, and that most successful innovations have multiple advantages (Hardman et al., 2013). In Ryan & Gross's study of the introduction of hybrid seed corn they found that adoption was successful due to the hybrid seed having more

than one relative advantage (Ryan and Gross, 1950). It is important that potential adopters understand the advantages of a new technology. The relative advantage of an innovation should be communicated to adopters so that they understand the benefits (Summer and Agarwal, 1997). Innovations therefore need to be targeted toward applications where their relative advantages are valued the most. Relative advantage is the most important consideration for early adopters; if they do not perceive an innovation as having relative advantage they will not adopt it (Freeman, 1995).

### **2.4.2 Compatibility**

This is the degree to which innovations are perceived as being consistent with existing values and beliefs, previous experiences and with existing needs of potential adopters. Incompatibility will result in slower rates of adoption (Saaksjarvi, 2003). Compatibility has been shown to be slightly less important than relative advantage in terms of an innovation's rate of adoption (Rogers, 2003). The first element of compatibility is that innovations need to be aligned with existing values and beliefs. Adopters will use existing knowledge to make comparisons and evaluate the new ideas based on what they already know. Secondly compatibility with previous experience is important, as it means consumers will be more likely to purchase the innovation. Dickerson & Gentry (Dickerson et al., 1983) undertook a study on the compatibility of home computers for adopters and non-adopters. They concluded that early adopters had existing experiences with similar technologies, for this reason they perceived home computers to be compatible.

The final component of compatibility is compatibility with needs. This is the degree to which an innovation is perceived as meeting the needs of the potential adopters. When needs are met, adoption is usually faster. Incorporated into this is awareness of needs. When adopters are aware of an innovation that can meet their needs they will seek adoption of this innovation. Compatibility is related to relative advantage; for example, if performance attributes are highly valued and a low performance product is introduced the innovation will not be compatible, so will not be adopted.

### **2.4.3 Complexity**

Innovations that are perceived as easy to understand and easy to use will achieve faster rates of adoption. Complexity is less important than relative advantage, and also less important than compatibility. Complexity refers to both the nature of the technology, understanding what the technology's features and benefits are and how it is used. A technology that is easy to understand, whose features and benefits are clear and that is simple to use will be more attractive to adopters (Rogers, 2003).

If complexity is high and it is difficult to communicate the idea to potential adopters this may have a negative effect on rates of adoption (Fliegel et al., 1966). High levels of relative advantage and compatibility can compensate for high complexity, meaning complex innovations can still be adopted. It is found that technological innovations are in general more complex (Saaksjarvi, 2003) which could be a reason for slower rates of adoption in some technological innovations. Through statistical analysis Allan and Wolf (Allan and Wolf, 1978) found that lower complexity means a higher probability of adoption. If innovations are complex they usually will be only adopted

by highly educated members of society (Fliegel et al., 1966), this is because these people will find it easier to make sense of them.

#### **2.4.4 Trialability**

This is the degree to which the innovation may be used on a limited basis before it is fully adopted. Greater opportunities for trialling a technology will lead to greater potential for adoption (Rogers, 2003). Trialability is especially important for early adopters and innovators who will be experimenting with new and unproven technologies; they therefore desire to experience the working innovation before fully adopting it (Ryan and Gross, 1950).

By being able to trial an innovation it is possible to discover unanticipated consequences of adoption. This can help mitigate possible negative effects of adoption, and allows positive aspects to be revealed and experienced by consumers. This means the potential adopters may be more likely to fully accept the innovation after the trial (Fliegel et al., 1966). Technological innovations are more difficult to test on a limited basis, this can be due to high cost (Dickerson et al., 1983). This lack of trialability can impede adoption rates. Schiffman (Schiffman, 1972) observed a relationship between trialability and risk. They found that increased opportunity for trial reduces the level of perceived risks associated with adoption and hence increased adoption rates.

#### **2.4.5 Observability**

The final attribute of innovations is observability; this is the capacity of potential adopters to witness the results of the innovation. This has two components, being

able to observe the innovation, and being able to observe the benefits of the innovation (Rogers, 2003). Being able to observe the benefits of the innovation will lead to even greater potential for adoption compared to just being able to observe the innovation (Dickerson et al., 1983).

Observability is the least important of the 5 attributes and the influence on rates of adoption has been contested. Allan and Wolf were not able to confirm that observability has a causal effect on rates of adoption (Allan and Wolf, 1978). But Rogers' does state that innovations with greater perceived observability will be adopted more rapidly than others (Rogers et al., 2005). Observability is important because it reduces ambiguity and uncertainty, which make an innovation seem less imposing to adopters and this according to Brockman & Morgan can increase motivation to adopt (Brockman and Morgan, 1995). Significant and easily observable benefits can be a strong motivating force for adoption.

#### **2.4.6 Early Adopters**

There are three types of innovation decision processes. The first is an optional innovation decision where an individual decides to adopt an innovation on his or her own. This is the decision with which this thesis is concerned, as it is a decision made by a consumer and the consumer is the user of the innovation. The other two types of innovation decision process are collective or authority. Collective is whereby a decision is made by all participants that would use the innovation, perhaps in a cooperative or small community. An authority decision is where the user does not decide whether they use the innovation, rather someone in a position of authority forces them to adopt. This would be the case for drivers of fleet vehicles, where their

superiors or fleet managers could make a decision that all drivers should now drive a certain type vehicle, for example.

It is necessary to consider who will adopt the innovation when considering the diffusion of innovations. Rogers suggests that there are 5 types of adopters, and that each of these will adopt the new technology at a different time. The first two groups to adopt are innovators and early adopters who are the first 2.5% and 13.5% of people to adopt. Often these two groups are combined to just early adopters (Rogers, 2003), and this is done in this thesis. The next group of people to adopt are referred to as the early majority (34%), followed by the late majority (34%) and finally laggards who are the last 16% of the market. These groups can be seen in Figure 2.2. The most important consumers are early adopters, without whom consumers would never adopt innovations. Therefore Rogers' theory concentrates on identifying and understanding early adopters, rather than the later groups of adopters, as do the results in this thesis.

Rogers' theory makes the following generalisations about early adopter socio-economic and psychographic profiles. It states that early adopters will be of higher education, have a higher social status, have greater upward mobility, be part of larger-sized social units than later adopters and possibly be younger than later adopters. Early adopters' psychographic profile is supposed to be one with a high level of empathy, high level of rationality, high level of intelligence, willing to accept change and have an open mind about science, amongst other things. The idea that the first people to adopt a technology are different to later adopters is supported by an abundance of research (Allan and Wolf, 1978; Brockman and Morgan, 1995; Dickerson et al., 1983; Fliegel et al., 1966; Freeman, 1995; Saaksjarvi, 2003;

Summer and Agarwal, 1997). There is also a large body of automotive adoption research that finds that the first buyers of new automotive technologies are different to the general population, as will be shown in the following literature review chapter, thus supporting Rogers' theory.

What Rogers' theory makes clear is that consumers who are early adopters of new technologies are remarkably different to later adopters. When considering the adoption of a new technology it is important to understand who the early adopters might be. Furthermore when gathering empirical evidence on automotive early adopters and consumer attitudes towards innovations it is important to target people who are early adopters rather than just sampling the general population who are unlikely have an early interest new technology.

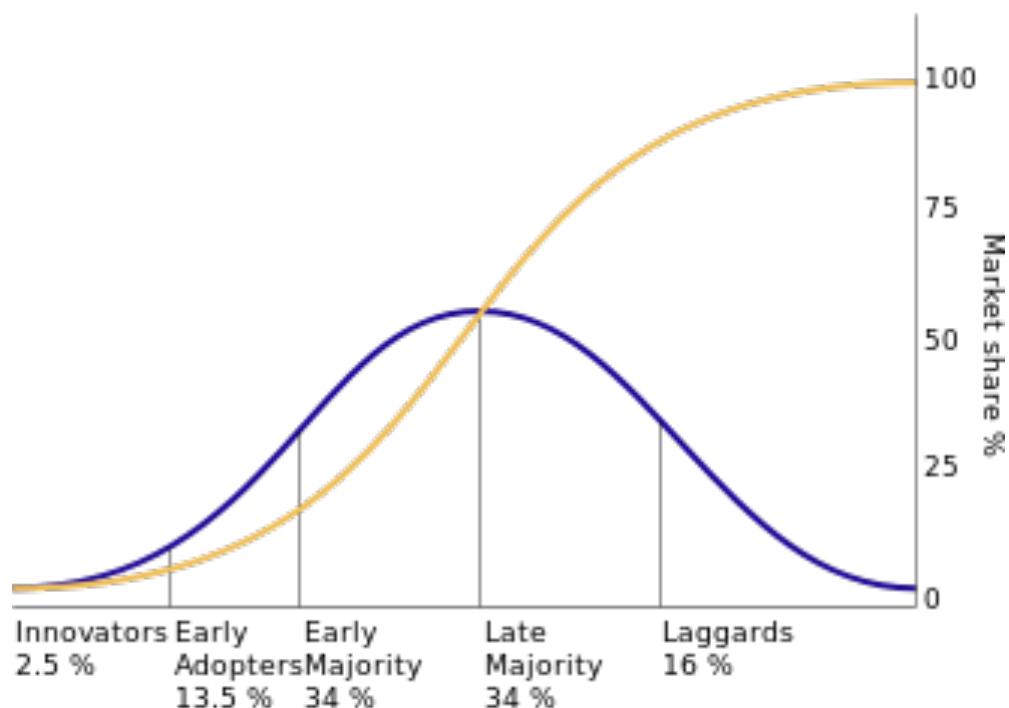


Figure 2.2: Rogers' classification of groups of adopters from innovators who are the first to adopt up to laggards who are the last to adopt an innovation (Rogers, 2003).

## 2.5 Consumer Perceived Value

Relative advantage is the most important attribute when considering innovation adoption success. However, within diffusion of innovation theory there is not a framework, procedure or criterion, which allows researchers to investigate whether a new product or technology has relative advantage. Rogers only defines the relative advantage as *“the degree to which an innovation is perceived as superior to an idea that is superseded”*. This means that the relative advantage of a product is open to interpretation and can be ambiguous. Diffusion of innovations is a theory that aids in our understanding of how new technologies diffuse through the market, however what is needed is a theory that understands why consumers purchase one product over a competitive product, or what has attracted them to that one product. The importance of this section of literature review thus is to help understand how relative advantage might materialise in a technology. Within marketing and psychology research this is referred to as consumer perceived value. This body of literature looks towards understanding what consumers value in products, technologies or services (Sweeney and Soutar, 2001). Perceived value is important for innovations, it contributes to the decision to adopt the technology for the initial purchase (Ram and Sheth, 1989). But value also leads to increased propensity to make repeat purchases (Rogers, 2003; Yang and Peterson, 2004). High levels of perceived value can give companies a strategic advantage over competitive firms (Sanchez-Fernandez and Iniesta-Bonillo, 2007). However within the literature there is no universally accepted measure for value (Sweeney and Soutar, 2001).



Consumer perceived value is a replacement for consumer satisfaction (Sanchez-Fernandez and Iniesta-Bonillo, 2007). Since the Early 1990s research has concentrated more on value rather than satisfaction. Satisfaction is less useful for researchers as it can only be used post-purchase, therefore cannot be predictive (Sweeney and Soutar, 2001). Value also includes economic aspects such as initial purchase price, which satisfaction did not (Eggert and Ulaga, 2002). Value is perceived by the consumer and is not objectivity determined by the organisation marketing or developing the innovation (Woodruff, 1997), hence there is a need for empirical evidence. It is understood to be a trade off between what the consumers receive and the sacrifices they make in order to access this (Eggert and Ulaga, 2002; Woodruff, 1997). It is therefore a compromise between benefits gained and costs incurred by the consumer. The contributors to benefits and costs are diverse, complex and are often debated within the literature. Costs are generally considered to be monetary payments, or non-monetary payments such as time, energy use, or stress (Yang and Peterson, 2004).

The perceived value of an innovation is complex due to the many factors that could contribute to the value of the innovation. Often the overall perceived value of a product is influenced by interrelated components of value (Sweeney and Soutar, 2001). Along with functional characteristics of an innovation, such as measurements of its performance, more subjective attributes will also contribute. For example the visual attributes of an innovation do not contribute to its functionality, but do still contribute to the value of the innovation if perceived as desirable by the consumer. There are a number of theories within the literature. For the most part the differences are slight, and in general there appears to be an agreement that value is something

that arises as part of an interaction between a consumer and a product. That value is also relative by virtue of its competitive, personal and situational nature. And that value is something, which is perceptual from the viewpoint of the consumer.

### **2.5.1 Uni-Dimensional versus Multi-Dimensional Value**

There are two streams of value literature, these are uni and multi-dimensional. Uni-dimensional value is where one single overall concept is considered to be contributing to the value of a product or service. This is more simple than multi-dimensional theories, which consist of several interrelated attributes or dimensions of a product such that it forms a more holistic approach of consumer perceived value (Rezvani et al., 2015). Uni-dimensional studies find their beginnings in economic theory. These theories consider consumers to be rational in their purchase behaviour. These studies consider value to be a result of the relationship between quality and price, or function and cost. These theories, although useful, are over-simplified and cannot account for more subjective reasons that motivate purchases and contribute to the overall value of a product. These theories are not used here, as it is clear than when the decision to invest in a new technology such as a AFV is being made their will be more contributions to the value of the vehicles than functionality alone. Multi-dimensional theories are more complex and take into account additional features of innovations. The theories also consider more subjective reasons for purchase such as social and emotional reasons. Within the multi-dimensional literature there are two prominent theories, these are Holbrook's Typology of Perceived Value, and The Theory of Consumptions values developed by (Sheth et al., 1991). Both of these theories are reviewed below.

## **2.5.2 Holbrook's Typology of Perceived Value**

Many consumer value studies and theories only consider value to result from the utilitarian benefits of a product, this is because early research believed consumers to behave rationally in all situations (Holbrook, 2006). Holbrook's typology of perceived value takes a more holistic approach and includes symbolic meaning and more subjective characteristics of a product. This research began in the early 1980s (Holbrook and Hirschman, 1982).

The theory suggests three dichotomies; extrinsic vs. intrinsic, self vs. other oriented and active vs. reactive. These dichotomies result in 8 values as shown in Table 2.1. According to Holbrook, all of these values can be present simultaneously, however, this will be at varying degrees of importance. These 8 areas are grouped as Economic, Hedonic, Social or Altruistic Value. Economic value is when a product serves as a means to consumer's personal objectives. This is either through efficiency, for example a reduction in running costs associated with a product. But it is also through the higher quality of a product, which is referred to as excellence. Social value is when a consumer's consumption behaviour serves as a means to evoke a response from others. For example increasing status through owning products of a prestigious brand. This could also be esteem enhancing, and Holbrook uses the example of having a luxury car visibly parked in front of one's house to boost self esteem (Holbrook, 2006). Hedonic value is pleasure experienced by the consumer for his or her own sake. This is a means to its end in itself and the consumers are doing it for solely their own enjoyment. This can be either play, which is the enjoyment of using the product itself. But it can also be aesthetic value,

prominent in the arts for example listening to music or owning a painting. Finally altruistic value is a concern for how an individuals consumption behaviour affects others, either ethically or spiritually. Holbrook (Holbrook, 1999, 1996) states that each of these are interrelated and interact with one another to form the overall perceived value of a product.

Table 2.1: Holbrook's three dichotomies and the 8 values that can be present in a product or service.

		<b>Extrinsic</b>	<b>Intrinsic</b>
<b>Self Oriented</b>	<b>Active</b>	Efficiency	Play
	<b>Reactive</b>	Excellence	Aesthetics
<b>Other Oriented</b>	<b>Active</b>	Status	Ethics
	<b>Reactive</b>	Esteem	Spirituality

### 2.5.3 Theory of Consumption Values

Sheth et al (Sheth et al., 1991) pioneered the theory of consumption values in the early 1990s. The theory identifies 5 values that influence how consumers value a product. These are functional, social, conditional, emotional and epistemic values. The authors state that consumers buy products due to the presence of one or more of these values. Consumers are believed to make informed purchase decisions by considering these multiple dimensions (Turel et al., 2010). Sweeney and Soutar (Sweeney and Soutar, 2001) used this theory to develop a tool for measuring value through the use of a multiple item scale. They chose this theory as the basis of their tool because they believe that the theory is the most effective means of exploring value.

(Sheth et al., 1991) state that increasing the number of these values present in a product will increase the overall value, but consumers are usually willing to accept a product that has a trade-off between the 5 values. It is also understood that if innovations are without value there will be resistance to the product and it will not successfully enter markets. This is something consumer perceived value shares with relative advantage. When consumers are purchasing a new product these 5 values are important at three stages of purchase decisions. These are the decision to adopt or reject the technology. The second is choosing between available product types of that technology, and finally a decision between brands of the available product. In each of these 3 stages the 5 consumption values all contribute to a consumers decision. The 5 values are outlined below (Sheth et al., 1991):

- Functional: The product's ability to perform its functional, utilitarian or physical purpose. Such values could be due to a vehicle's speed, acceleration, range, number of seats etc.
- Social: This is the consequence of what the technology communicates to others. This may be a technology with a positive social image. For example a particular vehicle may be chosen over another due to the image it evokes, and not just functional considerations.
- Emotional: This is the capacity of a product to arouse feelings or cause an affective state within a consumer. A product will gain emotional value when associated with specific feelings. This could be positive such as enjoyment or pleasure or the positive feeling due to driving a low emission vehicle.
- Epistemic: This is to do with the aspiration for knowledge; this could be due to intellectual curiosity or by seeking something innovative. Early adopters of

technologies often hold these values. Innovators who aspire to purchase new and innovative technologies exactly because they are new and innovative hold these values. FCs may appeal to these groups.

- Conditional: This relates to the functional and social values, when a set of unique conditions creates temporary functional or social values. An example of this could be high fuel prices resulting in AFVs being valued higher than previously due to their low running costs.

In order to increase consumer uptake there are three potential strategies for increasing the level of perceived value. The first of these is to increase the value of an innovation by providing significant value over incumbents. The second is to reduce costs, such that the level of value is perceived as higher due to reduced financial costs. Finally it is possible to increase value by positioning a product in the most appropriate market (Ram and Sheth, 1989). If organisations fail to incorporate value into products market entry will not occur as there will be no incentive for consumers to change (Ram and Sheth, 1989).

## **2.6 Summary**

This chapter reviewed 4 areas of literature that are important for this thesis; these were disruptive innovation, high-end encroachment, diffusion of innovations, and finally consumer perceived value literature. These theories allow an improved understanding of the market entry of new technologies or innovations. They also allow an understanding of who may adopt an innovation and also why consumers may be attracted to an innovation due to the value they perceive in it.

Of the theories reviewed, diffusion of innovations or Rogers' theory is the most popular, and indeed the most widely cited with almost 70,000 citations. Rogers' theory is useful for this thesis as it outlines what types of consumer will be early adopters, which will be helpful in considering the market entry of FCVs. The theory also outlines 5 attributes that innovations need to possess in order to achieve market entry. This theory therefore is used the most within this thesis. The others are nevertheless still useful in understanding the market entry of FCVs. Rogers' theory does not provide a descriptive enough account of relative advantage, therefore consumer perceived value literature was reviewed. Of the theories reviewed on this topic the theory of consumption values (Sheth et al., 1991) is the most thorough description of what consumer may value within a product and this finds that consumers will purchase a product due to some functional, emotional, social, epistemic or conditional values they perceive.

# CHAPTER 3

Literature review- Alternative fuel vehicle  
consumer adoption



## **Chapter 3    Literature Review- Alternative Fuel Vehicle Consumer adoption**

### **3.1    Introduction**

This chapter considers literature that can broadly be referred to as research into the consumer adoption of AFVs. It covers a variety of topics including identifying early adopters, considering how much consumers are willing to pay for BEVs, barriers to adoption of new technologies, amongst other issues. This chapter considers a variety of literature covering HEVs, PHEVs, BEVs and FCVs. These vehicles are referred to collectively as AFVs, but where necessary HEV, PHEVs, BEVs and FCVs are specifically referred to for clarity. All of these AFVs are included in the review as they share a number of characteristics meaning that consumers may perceive them in a similar way. Therefore the literature from each sector is potentially transferable and relatable to the other technologies. They are also all recent innovations within the automotive sector.

The newest commercial market entrants are BEVs, with FCVs promising commercial market entry in the coming years, with low volume production beginning now. The environmental benefits of BEVs are clear, in order for them to have the biggest impact on greenhouse gas emissions and local air pollution mass-market entry is necessary. In order for BEVs to take mass-market shares, they need to be accepted by consumers. In order to assess the adoption of BEVs it is becoming increasingly important to gather data from first hand users (Rezvani et al., 2015). A study into different German consumer groups found that it is currently not clear whether BEVs

will receive enough support from consumers in order to gain significant market shares (Peters and Dütschke, 2014), and therefore achieve mass market entry. Research into BEV adoption is needed in order to analyse this to reduce uncertainty (Greene et al., 2014). Empirical data will be essential in performing this task.

The electric vehicle literature currently lacks empirical data from owners of BEVs. Much of the existing data explores purchase intentions (Browne et al., 2012; Hahnel et al., 2014), preferences of potential adopters (Koetse and Hoen, 2014; Ozaki and Sevastyanova, 2011), barriers to adoption (Egbue and Long, 2012), opinions on BEVs from potential adopters (Chorus et al., 2013), and how financial incentives may influence adoption (Kihm and Trommer, 2014; Sierzchula et al., 2014). The majority of the literature investigates intentions for adoption by people who have not yet owned or driven an AFV. There is much less literature which uses empirical data from actual owners of BEVs, who would be the typical early adopters. The authors of a 2015 review on consumer electric vehicle acceptance (Rezvani et al., 2015) found that empirical data from adopters of BEVs was extremely scarce within the literature. According to their review the largest sample of BEV owners within the literature at that time was a sample of 80. However the author of this thesis was able to identify a study by Peters and Dütschke (Peters and Dütschke, 2014) involving 92 users of BEVs within a large sample of non-users. A further study by (Lane et al., 2014) explored 76 users of THiNK electric vehicles in Indiana, USA. (Peters and Dütschke, 2014) also call for more research involving actual adopters of BEVs, in particular on whether adoption leads to improved perceptions of BEVs.

This review first explores literature that attempts to identify and understand what types of people will be early adopters of AFVs. Second it explores literature that

looks to understand purchase motivations of early adopters, and perceived barriers to adoption. Then it explores papers that aim to understand what premium early adopters are willing to pay for a BEV, and the importance of purchase incentives in the decision to purchase a BEVs. Finally, studies that use data from persons who have experience with an AFV are explored, followed by exploring literature that investigates FCV market entry. The review ends with a summary of the current limitations of literature in this field of research.

### **3.2 Identification of Early Adopters**

Information on the identification of early adopters of BEVs, is useful in developing and growing the market. A number of early studies, based in the USA, explored characteristics of potential early adopters by interviewing multi-car households (Kurani et al., 1994, 1996). The authors predicted that early adopters of BEVs would be households with 2 or more cars and have a garage where at least one car can be parked. Multi-car households were identified as an early market because of the limitations of a BEV, particularly with short ranges of around 100miles, meaning having a single BEV would be potentially challenging for the owners. Having a garage was important so that a BEV can be charged in a suitable location.

Another study in the USA by (Carley et al., 2013a) gathered data from 2302 people. From their sample they concluded that early adopters are likely to be highly educated, environmentally sensitive and would already tend to be owners of a HEV. Studies, in Germany, by Plötz et al involving 210 people with 'high interests in BEVs' (Plötz and Gnann, 2011; Plötz et al., 2014) predicted that early adopters would be middle-aged males, in technical professions, in rural or suburban multi-person

households. This was contrary to a previous study by that concluded that early adopters would be from major urban areas (Plötz and Gnann, 2011). They recommended that BEVs should be marketed as family cars.

A study of US residents over 17 years of age by Hidrue (Hidrue et al., 2011) predicted that early adopters would be young, educated, have green life styles, and fuel cost concerns. These authors found that, contrary to previous studies, high income and multiple car ownership wouldn't be necessary. They also found a high willingness to pay for a BEV with good range, fast charge times, with fuel cost savings, pollution reductions and good performance. Another study in the US sampled 1000 members of the general public in order to understand the potential PHEVs have for market entry (Krupa et al., 2014). A UK based study by Campbell (Campbell et al., 2012) used national census data in order to identify locations of early adopters. They identified people who were homeowners, drive to work, own 2 or more cars, have a high socio-economic status, and are highly educated.

### **3.3 Purchase Motivations & Barriers to Adoption**

This literature explores consumer motivations and barriers to the adoption of a BEV. This is important in understanding which attributes are viewed as the most beneficial by consumers and also which are the most significant barriers. Understanding this assists policy makers and automotive OEMs in developing the next generations of BEVs and policies to support their introduction. The previously mentioned study by Carley (Carley et al., 2013a) predicted intent to purchase a BEV based on a sample of 2302 members of the general public. In this study the authors asked respondents to rank the 3 most important vehicle attributes from a list of 16. It was found that the

main disadvantages of BEVs at present were high cost, long charge times and short ranges. The main advantages of BEVs were fuel economy, environmental image and being at the cutting edge of technology.

Egbue & Long (Egbue and Long, 2012) sampled 500 'technology enthusiasts' in USA, who owned ICEVs, to determine attitudes towards BEVs. These enthusiasts were viewed as potential early adopters of BEVs. They found from their sample that sustainability was less important than purchase price and vehicle performance. The respondents had negative associations with BEV technology. These were high costs, limited battery life, low range, long charge times and the electricity used for charging being generated using fossil fuels. The biggest concern about BEVs was range with 33% of respondents citing it as a barrier to purchase. They also found that social barriers might be as important as technical barriers. The most significant obstacles to market entry were found to be a lack of knowledge of BEVs, high costs and low risk tolerance of potential adopters towards the new technology (Egbue and Long, 2012).

A 2011 study by Ozaki and Sevastyanova (Ozaki and Sevastyanova, 2011) investigated the adoption of HEVs and not BEVs. The researchers gathered data from 1263 owners of the Toyota Prius in the UK. They found that the main driving force for adoption was economic motivations; these were realised through fuel and tax savings. An investigation by Kurani (Kurani et al., 2008) also studied HEVs, this time 23 drivers of prototype Toyota Prius' PHEVs. (Axsen and Kurani, 2013) investigated consumer demand for HEVs, PHEVs and BEVs. They found that consumers were most interested in PHEVs out of these three technologies. Low consumer interest in BEVs was due to perceptions of low range, high purchase price and because BEVs were considered an unproven technology. These findings came

from web based design games from 508 households in Southern California. A further study by the same authors interviewed 10 households. In this study (Axsen and Kurani, 2011) conceptualised the benefits of an AFV into two areas; Functional and Symbolic, and Private and Social. Functional benefits are benefits that include financial savings, but also performance. Symbolic values are what the vehicles image communicates to others. Private are benefits only experienced by the consumer, such as financial savings (functional) but also positive feelings towards the vehicles having a positive environmental image (symbolic). Social values are ones that can be experienced or witnessed by others, such as observations of the symbolic values. (Axsen and Kurani, 2011) present this in the following table.

Table 3.1: Conceptualisation of the benefits of an AFV (Axsen and Kurani, 2011)

	Functional	Symbolic
<b>Private</b>	Saving money Performance	Expression of self identity Convey personal status
<b>Social</b>	Reduce Air Pollution Reduce Global Warming	Inspire other consumers

(Lane et al., 2014) reported that early adopters and fleet users of BEVs valued the environmental friendliness of the vehicles, and simply being early adopters of a new technology. The advantages of BEV ownership were found to be saving money, environmental protection, their high-tech nature, low maintenance costs, and fun/enjoyable driving style. They found the following disadvantages of BEV ownership:

- low range

- high purchase prices
- long recharge time
- problems in getting access to home and public charging
- expense of charging
- low speed
- small size
- low power
- poor crash safety
- poor cabin and cargo space
- lack of maintenance infrastructure

Further to these shortcomings (Larson et al., 2014) found that high price, lack of reliability, poor range and high battery costs were a barrier, agreeing with some of (Lane et al., 2014) findings.

From a study by (Turrentine et al., 2011) it emerged that users of the Mini E value the high performance nature of the vehicle (acceleration), the good handling and the fact that these driving characteristics were available with a vehicle that has low environmental impacts. It also emerged that the regenerative braking meant that for much of the time acceleration and deceleration could be easily controlled using only one pedal, making it more convenient to drive. Members of the study were found to look favourably on BEVs post trial, with the entire sample agreeing that BEVs were suitable for daily use.

Most of the benefits mentioned are functional in nature, they arise from the attributes of a BEV, however some motivations are symbolic. A number of studies by (Heffner et al., 2006, 2005, 2007) identified symbolic benefits of AFV ownership. The authors

challenge the notion that consumers buy AFVs to save money or for some other rational reasons. They argue the importance of the symbolic meanings that vehicles communicate to others. It is found that AFVs communicate a number of things that can include a positive environmental attitude, being frugal, smart consumerism, conscientiousness, caring for others and opposing war. Owning an AFV can give consumers a greater feeling of self-image as the vehicles can communicate the aforementioned symbols to others according to Heffner.

### **3.4 Willingness to Pay for Battery Electric Vehicles**

BEVs clearly have beneficial attributes when compared to ICEVs. As a new technology this comes at a cost, namely high prices for early generations of products entering the market. The reasons for this are the lack of economies of scale, at least in the early market, and the necessity for OEM's to reclaim at least a part of the development costs during this phase of market entry. Therefore early adopters will be required to pay a price premium to access the novel technology at this early stage of the market. The actual monetary value of the beneficial attributes to consumers is not widely understood (Kurani et al., 1996). Whilst this statement was made in 1996 it still remains true today, with existing studies only hypothesising what consumers might pay, for example the studies by (Hidrué et al., 2011) and (Potoglou and Kanaroglou, 2007). There are no studies that explore what consumers have actually been willing to pay for a BEV compared to an ICEV. The existing data comes from attitude surveys. These are only representative of consumers' ideals therefore they are not a true representation of their actual purchase decision processes (Kurani et al., 1996).



An early study (Kurani et al., 1994) found that consumers may not be willing to pay any premium at all for BEVs. After gathering more evidence through qualitative data collection this suggestion was modified in a later study by the same authors (Kurani et al., 1996). The work tested demand for BEVs in multi-car households. It was suggested that consumers would be willing to pay a US\$5,000 premium for a BEV. (Turrentine and Kurani, 2007) investigated the relationship car buyers have to fuel economy. This study found that consumers were willing to pay US\$0-10,000 for a 1.5 times increase in the efficiency of their vehicles. They found that almost all respondents did not exhibit any behaviour that could be considered economically rational. Most people came to a rash approximation, which resulted in an over-estimation of potential cost savings, and an over-calculation of current fuel expenditure. Indeed they found that most vehicle buyers do not consider fuel economy and running costs when purchasing a new vehicle. For these reasons they were willing to spend more on an efficient vehicle than they would receive in cost savings over time. This means that the initial investment would not receive a financial return. A proportion of the persons in this study were owners of HEVs. It was found that even these individuals placed a higher value on the fuel economy of their vehicles than what they received in running cost reductions.

A study by (Potoglou and Kanaroglou, 2007) investigated the demand for clean vehicles and the willingness to pay for different attributes of them. They found that consumers were willing to pay a premium of US\$500-1,200 to save US\$100 per year on maintenance costs, US\$2,200-5,300 to save US\$1,000 in annual fuel costs, US\$2,000-5,000 in order to not pay vehicle/road tax, US\$500-760 for a vehicle with a 1 second reduction in 0-60 acceleration, and US\$2,000-5,000 for vehicle with 90%

less emissions compared to an ICEV. This means that, simply speaking, if consumers were to purchase a BEV with all of these attributes they would be willing to pay a premium a maximum of US\$7,200-16,500 compared to an incumbent ICEV.

A 2011 study by (Hidrué et al., 2011) used stated choice experiments where consumers were given a selection of hypothetical BEVs, with varying attributes and prices, to choose from. The sample in this study was the general population. They concluded that consumers were willing to pay US\$6000-16,000 for a BEV with the desired attributes of their choosing. Consumers were willing to accept these price premiums not for environmental, or green reasons. The main motivation of consumers in this study was to achieve fuel savings. A more recent publication by (Larson et al., 2014) presented data from consumer attribute surveys administered in 2011 and 2012. This paper explored two methods of BEV valuation. These were the price sensitivity method and the willingness to pay method. From the first method it was found that consumers would pay a purchase price of US\$22,000-27,500 for a BEV. These figures are inline with the purchase price for a conventional ICEV. Their second methodology found that consumers might be willing to pay a premium of US\$10,000, though.

From existing literature it does appear that consumers will be willing to pay some premium for a BEV, or at least will pay the same for a BEV as compared to an ICEV. There are considerable differences in the figures calculated, though. With some data suggesting consumers will not pay a premium for a BEV (Kurani et al., 1994; Larson et al., 2014), but others suggesting that consumers will be willing to pay up to US\$16,500 more for a BEV over an ICEV (Potoglou and Kanaroglou, 2007). Table 3.2 summarises the ranges of figures reported for willingness to pay. Many of the

studies are now dated and even the newest is 2 years old. Studies pre- 2008 would not have been able to consider Tesla Motors as this was the first year that their first vehicles, the Tesla Roadster was sold.

Table 3.2: Consumer willingness to pay a premium for a BEV taken from the literature.

Author(s)	Willingness to Pay
(Kurani et al., 1996)	US\$5,000
(Turrentine and Kurani, 2007)	US\$0-10,000
(Potoglou and Kanaroglou, 2007)	US\$7,200-16,500
(Hidrué et al., 2011)	US\$6,000-16,000
(Larson et al., 2014)	US\$0-10,000

### 3.5 The Importance of Purchase Incentives

In many nations financial purchase incentives are currently being utilised as policy interventions designed to increase the uptake of BEVs, these incentives have also been used to support HEV and PHEV market uptakes and are still used today. (Diamond, 2009) looked at the importance of purchase incentives for HEVs in the United States. They found that it was difficult to assess whether the incentives have an effect on sales due to confounding factors such as increases in the price of petroleum and other benefits of HEV ownership such as HOV (High Occupancy Vehicle) lane access. The authors concluded that both state incentives and petroleum prices have an effect on HEV sales. Similar studies found that state incentives do explain the market share of HEVs, but petroleum prices are also an important factor (Berestenau and Shanjun, 2011; Gallagher and Muehlegger, 2011). A study by (Jenn et al., 2013) concluded that there must be tangible benefits to

owning HEVs, not just purchase incentives . In this case the benefit was fuel savings. Their conclusions were brought about by the observation that the incentive has a greater effect for HEVs with higher fuel economy.

A study that assessed potential demand for BEVs through the use of a survey found that 82% were likely to buy a BEV if state and local incentives were available (Krause et al., 2013). That figure appears to be an overestimation of the incentive effectiveness based on actual sales figures. (Green et al., 2014) found that the policies for BEVs in the United States were both inefficient and ineffective in increasing sales figures. One reason for this is because the US\$7,500 federal incentive is in the form of a tax credit and only 40% of households have a tax liability of more than US\$2,500 meaning the benefit to most households was marginal. A additional study was in agreement with these conclusions (Deshazo et al., 2014). (Deshazo et al., 2014) recommend that an aggressive rebate with an income cap would be the most effective policy. They suggested a US\$5,000 rebate for household with incomes <US\$100,000 and US\$0 for households with higher incomes. They also suggested a vehicle purchase price eligibility cap of US\$60,000, but the former income cap was more effective. The authors believed that an aggressive price cap strategy could save US\$77 million per year and not harm BEV sales.

An assessment of BEV adoption in 30 countries found that the relationship between incentives and BEV adoption rates were statistically significant (Sierzchula et al., 2014). The authors also found statistically significant relationships between BEV adoption and the presence of charging infrastructure, income and level of education. They summarised these findings by suggesting that both purchase incentives and developing charging infrastructure will result in the greatest impact on BEV sales.

Indeed purchase incentives do appear an effective tool in increasing the market share and demand for BEVs (Brand et al., 2013; Collantes and Eggert, 2014).

There appears to be disagreement within the literature as to the importance of incentives for BEVs, unfortunately there is no evidence from early adopters. This evidence is needed to assess the importance of the purchase incentives to these individuals on a factual basis. The author of this thesis has been unable to identify any publications that sample actual early adopters of BEVs in order to investigate the importance of the incentives to them. Such a study would bring about more reliable data and would also build on the understanding of how people perceive these incentives and how much they factor into the decision to adopt a BEV.

### **3.6 Studies with Early Adopters**

There are a limited number of studies that use empirical data from persons with first hand experience of a BEV. This experience mostly comes from vehicle trials but also from fleet vehicle use. There are a few studies that indeed include actual owners of BEVs, Table 3.3 shows a summary of this literature.

Work by (Turrentine et al., 2011) investigated members of the Mini E trial in the US. The goal of the study was to understand user responses to BEVs and to identify a route to market for them. 54 Mini E drivers took part in the study; data was collected using driving diaries, online questionnaires, and phone and in-person interviews. The members of the trial leased the Mini E for a period of 1 year. According to the authors, this was the largest data set of its kind at that time. The results of the trial were positive with 71% of the sample indicating that they were willing to adopt a BEV after the trial. In addition to this, 64% of respondents indicated that they planned on

purchasing a BEV in the next 5 years. A further study on the Mini E was done in Germany (Bühler et al., 2014); this involved 79 participants in a 6 month trial. Respondents were interviewed before the study, 3 months into the study and after the 6 month period had ended. According to the authors, this was the only study that recorded changes in BEV perceptions over time. Their results are encouraging and suggest that experience with a BEV does improve perceptions, intent to purchase, and the likelihood of recommending a BEV to others. However, they did find that high purchase prices and limited range still represented a barrier to adoption.

A study carried out in the UK gathered data from 40 members of a vehicle trial. In this study 20 people were given a PHEV and 20 people a BEV for a period of 7 days. All participants in the study were drivers of ICEVs. From qualitative interviews it was found that respondents believed that purchase prices were too high. They indicated that if they were to remain high, the vehicles attributes should reflect this high price. The vehicles would therefore need to have higher performance, better looks, improved durability and a better driving experience (Bühler et al., 2014). Another study in the UK, by (Axsen et al., 2013) involved a sample of 21 people who had experienced a BEV. These experiences were either visual or from driving a BEV. In this sample only 8 interviewees had driven the BEV. The purpose of this study was to understand the importance of interpersonal communication in spreading awareness and knowledge of BEVs.

A study by (Lane et al., 2014) gathered data from actual early adopters of BEVs. In their sample 59 of the 76 respondents were BEV owners, and the remainder were fleet users of BEVs. This study therefore used data from people who had fully

adopted a BEV. It concentrated on early adopters of the THiNK City, a compact BEV, and found that perceptions of the vehicles were positive.

A study by (Caperello et al., 2013) investigated 'charging etiquette'. The study explored data from 29 interviews with BEV owners discussing experiences and problems faced with using public charging infrastructure. A 2014 study by the same author (Caperello et al., 2015) involved a sample of BEV owners and a sample of ICEV owners. This study looked at ways to bridge the information gap between early adopters and laggards by holding focus groups between the two sets of people.

Two US studies by (Tal and Nicholas, 2013; Tal et al., 2014) were not identified by (Rezvani et al., 2015) in their review of the BEV literature, perhaps due to these two papers being published in *The Journal of the Transportation Research Board*, which is a publication of the Transportation Research Board Annual meeting. Indeed, the author of this thesis was unable to locate these papers online and was made aware after verbal communications with the authors. These papers actually have the largest samples of BEV adopters within the literature, and predate the publication (Hardman et al., 2016) which claimed to have the largest sample of BEV adopters at that time. (Tal et al., 2014) gathered a sample of 3500 early adopters of HEVs and BEVs using an online survey. Respondents were recruited by email and by post using a database of BEV drivers provided by the California Air Resource Board (CARB). The sample was mostly BEVs with 2100 of them being Nissan Leaf BEVs, and the remainder being Toyota Plug-in Prius and Chevrolet Volt PHEVs. The publication explores BEV and PHEV drivers vehicle charging behaviour in order to determine how drivers of PHEVs use their vehicles compared to drivers of BEVs. Although the sample size is

larger than that in (Hardman et al., 2016) the topics of the studies differ, meaning that the results in that paper and in this thesis are still unique.

Table 3.3: Studies having a sample of actual BEV users within the current BEV adoption literature.

Author(s)	Method(s)	Sample Size	Sample Attributes
(Aksen et al., 2013)	Interviews	21	8 people who had driven a BEV within a total sample of 21
(Bühler et al., 2014)	Interviews	79	German Mini E Trial Participants
(Graham-Rowe et al., 2012)	Interviews	40	7 Day PHEV & BEV Trial Participants in the UK
(Lane et al., 2014)	Interviews	76	59 BEV Owners and 17 BEV Fleet Users in USA
(Turrentine et al., 2011)	Interviews, Questionnaires and Diary's	54	USA Mini E Trial Participants
(Peters and Dütschke, 2014)	Questionnaire	92	92 BEV users in sample of 969 people with high likelihood to purchase a BEV in Germany.
(Caperello et al., 2015)	Workshops	Not stated	General Population and BEV adopters in USA
(Tal et al., 2014)	Questionnaire	3500	2100 BEV and 1400 PHEV drivers in USA
(Caperello et al., 2013)	Interviews	29	BEV Adopters in USA

### 3.7 Fuel Cell Vehicle Adoption Literature

As has been shown, literature investigating consumer responses to AFVs has been published for over two decades (Kurani et al., 1994), with the vast majority of this research investigating hybrid electric vehicles (HEVs) (Caperello and Kurani, 2012; Graham-Rowe et al., 2012; Heffner et al., 2007) and BEVs (Campbell, 2014a; Caperello et al., 2015; Egbue and Long, 2012; Hardman et al., 2016; Hidrue et al., 2011; Plötz et al., 2014; Skippon and Garwood, 2011; Turrentine et al., 2011). The body of research investigating consumer responses or perceptions toward FCVs is far more limited. The majority of studies assess the perceptions of members of the general public who have no experience of a FCV or even an AFV (such as a BEV or



PHEV). Some studies investigate consumers who have been on a FC powered bus or taxi, and one study assesses the perceptions of consumers who have driven a FCV in a trial study. The earliest studies considering consumer responses to FCVs found cost to be a barrier to market entry (Chalk et al., 1996). The lack of refuelling infrastructure is also mentioned as a barrier (Chalk et al., 2000). An early study by (Schulte et al., 2004) drew on lessons from the introduction of other technologies and then made interpretations for FCVs. They found that successful market introduction is dependent upon consumer acceptance and infrastructure development (Schulte et al., 2004). They also found that the public's opinion of FCVs is likely to be different from that of the scientific communities. They believed that for this reason the general public might have safety concerns, which may hinder acceptance. They suggest that education and marketing activities could increase consumer acceptance. These results are based on case studies or the opinions of the authors and do not contain empirical evidence from consumers.

Literature that gathers data from consumers, rather than from case studies, can be more insightful in understanding consumer perceptions. A study by (Altman et al., 2004) looked to assess the perception of hydrogen and FCVs in three different countries. The researchers administered consumer surveys in locations where FC bus trials were underway. The findings from Luxembourg, the UK and Australia indicated that in general there is support for FCVs. They found that there were no objections to FCVs and that consumers believed hydrogen to have positive environmental impacts. O'Garra et al (2005) assessed consumer attitudes toward FCVs in the UK through the use of a survey which yielded 400 responses. An initial finding was that less than 20% of the population had heard of hydrogen and FCs

(O'Garra et al., 2005), but that perceptions of the technology were positive. Two German studies also found that consumer attitudes toward hydrogen were generally positive and there were no safety concerns with the public (Altman et al., 2004; Dinse, 2000). A study based in Stockholm, which gathered data from people who have ridden on a FC bus, came to the same conclusion (Haraldsson et al., 2006). A study of London Taxi drivers by (Mourato et al., 2004) found that cost could be a barrier to FCV market entry and that in order for Taxi drivers to adopt FCVs they would need to be financially comparable to ICEV Taxis. The Taxi drivers were found to not have any safety concerns about hydrogen as a vehicle fuel. A study by Campbell (Campbell, 2014a; Campbell et al., 2012) in the UK firstly identified locations in Birmingham with a high proportion of persons with socio-economic profiles similar to early adopters using census data, and then administered a survey to this area with 400 responses being received. The findings of this were that intent to adopt was low and that only 8% of these consumers had good knowledge of FCVs.

Within the literature there appears to be only one consumer study that samples people who have actually experienced a fuel cell passenger vehicle. The study by Martin et al (Martin et al., 2009) allowed consumers to ride in a FCV, drive a FCV and witness how the vehicles are refuelled. The study recruited 182 participants and conducted pre and post-ride and drive interviews. Consumers did not have safety concerns and the ride and drives were found to improve consumer's opinions about FCV performance. The researchers acknowledge that, in 2009, there was limited published research in this area and highlight the need for more studies working towards understanding consumer perceptions of FCVs.

There are also some explorative studies that investigate members of FCV trials. These studies are not academic publications. Two studies by the UK's Centre for Excellence in Low Carbon and Fuel Cell Technologies (Cenex) explored users involved in two different FCV trials, the first being the trial of London Taxis (Speers and Fijiwala, 2015) in the UK and the second being trials of the Hyundai ix35 FCEV in Copenhagen (Speers, 2015). They found that drivers like the smooth and silent drive of the vehicles, however there were concerns about the vehicle range with drivers stating that it was too short, and that the range calculation given by the vehicle was inaccurate. Drivers stated that there is not enough refuelling infrastructure and existing stations can be unreliable. None of these users are early adopters of automotive innovations rather they are fleet users of the vehicles.

The literature identifies three specific barriers to fuel cell market entry, these are the development of infrastructure, cost reductions and perceptions of safety (Ball and Wietschel, 2009; Chalk et al., 2000; Huijts et al., 2012; Keles et al., 2008; Melaina et al., 2012; Roche et al., 2010). (Schulte et al., 2004) also identifies 'consumer acceptance' as a barrier, a vague term that offers little in the way of what these barriers might be. It is a potential shortcoming of the literature that only three barriers to FC market entry have been identified. A socio-technical system as large and complex as the automotive sector contains a diverse array of consumers, who are likely to have a wide range of perceptions of FCVs. A reason for the literature only identifying three barriers to FCV market entry could be due to the consumers in all samples not being automotive early adopters. Previous studies merely ask general consumers about their perceptions of FCVs. Because these consumers do not have experience with an AFV their answers lack the depth and reliability one would expect.

They have to answer questions based on their estimations of reality and not due to some existing experiences that they have.

Table 3.4 shows a summary of FCV literature, which gathers data from consumers, rather than making suggestions based on opinion or case studies. These studies either use questionnaire surveys or telephone interviews to gather the data. These methodologies are sometimes unable to gather as rich and detailed data compared to in-depth qualitative in person interviews. Secondly the current literature is limited because it samples members of the population and not early adopters. This means that the perceptions of the consumers will not be representative of the perceptions actual vehicle adopters.

Table 3.4: Outline of fuel cell vehicle literature that gathers quantitative or qualitative data from consumers.

Author	Sample Size	Sample Characteristics	Methodology
(Dinse, 2000)	Not Stated	Employees of BMW Group	Questionnaire Surveys
(Altman et al., 2004)	Not Stated	Members of the general public in cities with FC bus trials	Telephone Interviews
(Mourato et al., 2004)	99	Drives of conventional (ICEV) Taxi's in London	Questionnaire Survey
(O'Garra et al., 2005)	420	Members of the general public in London	Telephone Interviews
(Haraldsson et al., 2006)	518	Members of the general public in Stockholm who have ridden on a fuel cell bus	Questionnaire Surveys
(Martin et al., 2009)	182	Participants in a ride and drive of a FCV in California.	Pre and post ride and drive surveys

## 3.8 Summary and Limitations of the Literature

### 3.8.1 Summary

This review outlined 6 main areas of literature that are of relevance to this thesis. The first identifies the types of people who are early adopters of BEVs. This is helpful in

understanding who will adopt future automotive technologies. At present the literature suggests that early adopters will have pro-environmental and pro-technology attitudes (Wolf and Seebauer, 2014), will be highly educated (Campbell et al., 2012; Carley et al., 2013a; Hidrue et al., 2011), have a high economic status (Campbell et al., 2012; Hidrue et al., 2011), have two or more cars (Kurani et al., 1994), be young to middle aged (Hidrue et al., 2011; Plötz et al., 2014), would likely own a hybrid vehicle (Carley et al., 2013a), have fuel cost concerns and be mostly male (Plötz et al., 2014). These generalisations are made without empirical evidence from actual early adopters and hence need to be verified. There are no studies that look to confirm whether these assumptions are valid by gathering empirical evidence from early adopters.

The literature identifies hypothetical motivations and barriers to the adoption of AFVs. This is helpful in understanding why consumers are attracted to AFVs and also what the barriers to the adoption of such a vehicle are. The main benefits of AFVs are found to be fuel economy and fuel savings, tax savings, owning the cutting edge technology, low maintenance, low environmental impacts, oil independence and opposing war, fun, performance, one-pedal-driving as well as symbolic reasons (Axsen and Kurani, 2011; Carley et al., 2013a; Egbue and Long, 2012; Heffner et al., 2007; Lane et al., 2014; Ozaki and Sevastyanova, 2011; Turrentine et al., 2011). Barriers to the adoption in the literature mainly explore BEVs, rather than PHEVs and HEVs. The barriers to adoption of a BEV have been identified as high vehicle and battery costs, long charge times, short ranges, perceived low reliability due to the technology being seen as unproven, small vehicle sizes, low top speeds, lack of maintenance infrastructure and poor crash safety ratings (Axsen and Kurani, 2011;

Carley et al., 2013a; Egbue and Long, 2012; Heffner et al., 2007; Lane et al., 2014; Ozaki and Sevastyanova, 2011; Turrentine et al., 2011)..

Generally, the literature agrees that consumers will be willing to pay some premium for a BEV. There are however disagreements on what this premium might be. In general, though, it is expected that consumers will be willing to pay somewhere between US\$0 and US\$16,500 more for a BEV over an ICEV (Hidrué et al., 2011; Kurani et al., 1996; Larson et al., 2014; Potoglou and Kanaroglou, 2007).

Financial considerations are an important factor in adoption, with studies citing cost as a barrier and also suggesting that consumers will pay a premium for a BEV. Therefore a consideration when researching AFVs is the various incentives that are available off the purchase price. There is disagreement within the literature with some studies suggesting that these incentives are important in increasing rates of adoption (Berestenau and Shanjun, 2011; Gallagher and Muehlegger, 2011; Jenn et al., 2013; Krause et al., 2013), however some studies present data to the contrary (Deshazo et al., 2014; Green et al., 2014).

This review then outlined studies that involve consumers who have actually adopted a BEV, these studies are less numerous than studies that sample potential adopters or the general public. Many of these are in trials and demonstration projects or the respondents are fleet users. Whilst these studies are helpful in understanding consumer responses to BEVs they are still not representative of an actual decision to adopt the vehicles as consumers. The studies identified that involve consumer who have actually adopted a BEV are outlined in Table 3.3.

Clearly there is a significant amount of literature that considers PHEVs, HEV and BEVs. This research, whether or not it includes samples of early adopters, has been helpful in guiding the growth of the market by making managerial and policy implications designed to increase market uptake. The same however cannot be said for FCVs, only one study exists within the literature that samples people with direct driving experience of a FCV. There are some studies that sample persons who have ridden on a FCV, though, and some unpublished explorative studies (Speers and Fijiwala, 2015; Speers, 2015). This lack of literature is clearly related to the immaturity of the market. As of the end of 2015 there were only 179 FCVs in the State of California (California Air Resources Board, 2015), the centre for FCV market development in the United States, and there were only 12 registered on UK Roads, 10 of these being Hyundai ix35s and 2 Toyota Mirai's. Clearly this makes data collection challenging, but not impossible. The data that does exist identifies a number of barriers to FCVs market entry including cost, lack of fuelling infrastructure, safety and low awareness of FCVs.

### **3.8.2 Limitations**

Currently within the literature, to the best of the author's knowledge, there is no data that explores the future vehicle purchase intentions of BEVs by current owners of BEVs. This data is important so that the diffusion of BEVs through the market can be understood, and will also reveal whether BEVs have enough relative advantage to convince adopters to continue with ownership. The majority of current BEV owners have purchased their vehicle as an initial purchase, having not owned a BEV previously. Subsequent purchases will be repeat purchases and it is known that the

way in which these purchase decisions are made is different from one another (Crawford and Benedetto, 2011). The literature does not explore this, there are no studies that investigate the likelihood of a repeat purchase of a BEV.

One of the most significant limitations of the literature is that early adopters are considered to be one homogeneous group of consumers. Within the literature early adopters are referred to as having shared socio-economic and psychographic characteristics, as they are in (Rogers, 2003). No single study makes distinctions between different possible groups of early adopters. This is despite the fact that BEVs range in price from US\$29,000 to US\$105,000 for a full sized BEV (Nissan, 2014; Tesla Motors Inc, 2014a). It is unlikely that an adopter of a US\$29,000 vehicle would be similar to the adopter of a US\$105,000 vehicle. Therefore this thesis addresses that major research gap.

Much of the literature is from persons who have no experience with an AFV. It is well established within the literature that attitudinal or predictive data is not representative of consumers actual behaviour (Bamossy and Solomon, 2013; Lane and Potter, 2007). More data is needed from consumers who have experience with an AFV, particularly with BEVs and FCVs as these vehicles are significantly different to ICEVs requiring new refuelling styles and having different user experiences, whereas PHEVs and HEVs can be used in much the same way as an ICEV. Further to this, there is currently no study within the literature that assesses what premium early adopters have actually paid for a BEV, rather it estimates and predicts what consumers might be willing to pay. Empirical evidence is needed from actual adopters in order to add to this literature. In many regions purchase incentives are available off the price of a BEV, often costing governments significant amounts.



There is currently no literature that asks early adopters about the importance of the purchase incentives that are available in their purchase decision. Asking consumers about the importance of such incentives would add value to the current literature. Finally, this thesis is concerned with investigating FCVs. However, there is a very limited amount of literature that considers the consumer acceptance or the adoption of FCVs. This is potentially seriously detrimental to the market introduction of FCVs.

Rogers' theory (Rogers, 2003) makes it clear that the first adopters of new technologies are remarkably different to the general population. Consumers who are the first adopters are called 'innovators' or 'early adopters'. Sometimes these two groups are combined to just 'early adopters'. The idea that the first people to adopt a technology are different to later adopters is supported by an abundance of research (Allan and Wolf, 1978; Brockman and Morgan, 1995; Dickerson et al., 1983; Fliegel et al., 1966; Freeman, 1995; Saaksjarvi, 2003; Summer and Agarwal, 1997). There is also a large body of research studying automotive early adopters that finds that the first buyers of new automotive technologies are different to the general population (Campbell et al., 2012; Caperello and Kurani, 2012; Carley et al., 2013a; Gnan et al., 2015; Hardman et al., 2016; Heffner et al., 2005; Hidrue et al., 2011; Kurani et al., 1996; Lane and Potter, 2007; Plötz et al., 2014; Turrentine et al., 2011; Williams and Kurani, 2007). Based on this evidence, stating that the adopters of new technologies and new automotive technologies are different to the general population, studies investigating consumer perception FCVs or any AFV should sample consumers who are actual early adopters, rather than members of the general public. This kind of methodology may yield results that are more representative of the attitudes of the

consumers who would actually adopt such an innovation, rather than people who are unlikely to adopt because of their status as later adopters of technology.

The lack of relevant literature is detrimental for the assessment of the growth of the FCV market. And poorly planned market introduction strategies could hinder the diffusion of FCVs (O'Garra et al., 2005; Schulte et al., 2004). An understanding of consumer perceptions toward FCVs is needed in order to make recommendations working towards an effective market introduction plan. A further limitation of the literature is that FCVs are considered only in the context of ICEVs. Despite ICEVs being the incumbent they are not the only automotive technology currently within the market place, BEVs are now taking market shares from ICEVs, and in some nations make up to 13% of all new vehicle sales (IEA, 2015). Therefore FCVs do not only need to be viewed as superior to ICEVs in order to be adopted they also need to be viewed as superior to BEVs. Indeed Roche et al (2010) had previously suggested that FCVs be considered in the context of other AFVs (Roche et al., 2010) so that the nature of them competing against each other in order to enter the markets can be properly considered. This competition between the two new technologies has thus far been overlooked.

# CHAPTER 4

## Methodology



## **Chapter 4 Methodology**

### **4.1 Introduction**

The research in this thesis uses three different methods, the first of which is historical case studies, the second is the use of questionnaire surveys, and then finally qualitative in-depth interviews. This chapter outlines how these methods are used to meet the aim and objectives of the thesis. The first objective, to examine how innovations have historically achieved market entry success, is met by conducting historical case studies that gather secondary data. The second and third objectives, to examine how battery electric vehicles are achieving market entry and to examine the potential of FCVs to do the same, are met using a combination of questionnaire surveys and qualitative in-depth interviews that gather primary data. The author of this thesis administered these interviews and questionnaires. The combination of both methods has been advocated for a number of years by social scientists (Bryman and Bell, 2015; Jick, 1979; Kaplan and Duchon, 1988; Steckler et al., 1992). Questionnaire surveys aim to gather large statistically representative samples, and in this thesis the online questionnaire survey yielded 340 respondents. Allowing this data to be explored with statistical analysis, with a margin of error of 5%. Qualitative interviews do not aim to gather a statistically representative sample, rather they look to gather in-depth information on a topic from a smaller sample size, and this thesis contains a sample of 39 interviewees. Combining these methods is beneficial as each one can compliment the other, partly by cancelling out the inherent shortcomings of each methodology but also by exploiting the benefits of each. The questionnaire respondents and interviewees in this thesis are all consumers who are

early adopters, they are therefore not representative of the general population, but they are representative of the first people to buy automotive innovations, and this was the reason for selecting this unique sample. There is one exception to this, and this is the sample in the questionnaire survey in chapter 12. These respondents are not early adopters, however as will be shown they are potential early adopters. Table 4.1 shows an overview of the methods used in each chapter along with the sample sizes of the primary data.

Table 4.1: Overview of the methods used in each results chapter of this thesis.

<b>Chapter</b>	<b>Method</b>	<b>Sample Size</b>
<b>5: Lessons from historical disruptive innovations</b>	Historical case studies of 7 innovations	Not applicable
<b>6: Fuel cell vehicles- Can lessons be learned from Tesla motors?</b>	Historical case study of Tesla Motors	Not applicable
<b>7: Mobile phone infrastructure development- lessons for the development of a hydrogen infrastructure</b>	Historical case study of mobile phone infrastructure development	Not applicable
<b>8: Comparing high-end and low-end adopters of battery electric vehicles</b>	Online questionnaire survey of BEV early adopters	340
<b>9: Exploring the premium paid for battery electric vehicles</b>	Online questionnaire survey of BEV early adopters	340
<b>10: An in-depth qualitative investigation into high-end battery electric vehicle adopters</b>	In-depth qualitative in person interviews with adopters of high-end BEVs	39
<b>11: A qualitative investigation into early adopters attitudes toward fuel cell vehicles</b>	In-depth qualitative in person interviews with adopters of high-end BEVs	39
<b>12: Consumer attitudes to fuel cell vehicles post trial in the United Kingdom</b>	Verbally administered questionnaire survey with FCV trial participants	30

## **4.2 Historical Case Study Methods**

The first data to be presented in this thesis is secondary data that was gathered using historical case studies. The data gathered comes from existing documents such as financial reports, memos, newspaper articles and reports. This research can be used to shed light upon events that have occurred in the past, and also ones that are occurring today where gathering first hand data can be challenging. Using existing documents in research allows an understanding of issues that are potentially complex to be gained relatively easily, meaning knowledge can be gained with little monetary and time expenditure. Historical case studies could not be used to formulate an entire thesis due to the limitations that they have. Clearly when using documents in study it will not be possible to uncover all issues about the topic. Therefore case studies are often used as a preceding method to primary qualitative or quantitative research. Nevertheless, they are valuable in building an understanding of a topic in order to guide the subsequent primary research, and can uncover emergent themes or information that may have previously been overlooked or simply not investigated by existing studies.

The use of historical case studies, sometimes referred to as simply 'historical analysis' (Bryman and Bell, 2015), in research is a widely discussed issue. (Flyvbjerg, 2006) presents a good case supporting the use of case studies as do (Shiu et al., 2009). (Gerring, 2007) presents a more detailed picture of the use of historical accounts to build case studies as part of research methods. These supporters believe that they are valuable tools for the researcher and that the findings of case studies can provide worthwhile. (Steinberger-Wilckens, 2002) used

historical case study methods when looking at disruptive technological market entry, this paper looked at small-scale photovoltaic cells, green electricity and double-glazing. (Geels, 2005) successfully uses case studies in order to create an improved understanding of technological change and (Melaina, 2003; Melaina et al., 2012) uses this method to understand the issue of infrastructural development. Historical case studies are valuable tools that can help researchers understand how to introduce innovations to the market. When using historical documentation the authenticity, credibility, representativeness, and meaning of the document needs to be considered and well understood (Bryman and Bell, 2015; Shiu et al., 2009). Any missing data has to be reconstructed or inferred but in most cases cannot be collected in retrospect.

The secondary research in chapter 5 is used to understand how innovations that are classified as disruptive innovations achieve market entry. There are many examples of successful disruptive innovations and in order to gain a broad understanding seven case studies of past successful disruptive innovations were undertaken. These case studies were selected due to similarities that the historical innovations have with FCVs. All of the historical cases are innovations that entered a market with an incumbent technology. The innovations were more expensive, had little infrastructure to support them and they all initially had some inferior attributes compared to the incumbent, but crucially also had key benefits. The 7 historical case study are on digital cameras, mass produced automobiles, hydraulic excavators, quartz watches, steam ships, eReaders and the iPod.

Chapter 6 concentrates on a specific example of a disruptive innovation. By looking at a more recent example of a high-end encroachment in the automotive sector, a

more in-depth understanding of how to introduce high value innovations will emerge. The main source of data in chapter 6 comes from financial reports compiled by Tesla Motors. Tesla files Form 10-K's once annually, Form 10-Q's once quarterly along with Form 8-K's on a monthly basis. A summary of the data sources used in this chapter is shown in Table 4.2. Tesla also release video footage of their annual shareholders meeting. These reports allow the company to communicate to investors. The reports contain a substantial amount of information including market analysis, financial data, sales volumes, order numbers, information on supplies and overall strategy of the company. These financial reports that are filed with the US Securities and Exchange Commission (SEC) are considered to be accurate and reliable. Laws and regulations surrounding the filings prohibit companies from reporting false or misleading information. To ensure compliance, the forms are reviewed and audited by the US SEC and are made available to the public. In order to further ensure the accuracy of the filings three accounting companies were requested to give advice on the reliability of such financial reports. The feedback from all three was that with current laws, regulations and audits the reports do not usually contain false information. In addition to this, the reports were sent to one of the companies so that they could in detail assess the credibility of the reports. Their assessment of this was that the reports could be considered to be accurate in their professional opinion.



Table 4.2: Outline of Tesla data sources.

Source	Type	Dates Filed	Data Available	Available From
Form 10K	Annual Report	March 2011, Feb 2012, March 2012, March 2013, Feb 2014, Feb 2015, Feb 2016	Company Strategy, Sales Volumes	<a href="http://ir.teslamotors.com/sec.cfm?DocType=Annual&amp;Year=&amp;FormatFilter=">http://ir.teslamotors.com/sec.cfm?DocType=Annual&amp;Year=&amp;FormatFilter=</a>
Form 10Q	Quarterly Report	Aug 2010, Nov 2010, May 2011, Aug 2011, Nov 2011, May 2012, Aug 2012, Nov 2012, May 2013, Nov 2013, May 2014, Aug 2014, Nov 2014, May 2015, Aug 2015, Nov 2015	Company Strategy, Sales Volumes	<a href="http://ir.teslamotors.com/sec.cfm?DocType=Quarterly&amp;Year=&amp;FormatFilter=">http://ir.teslamotors.com/sec.cfm?DocType=Quarterly&amp;Year=&amp;FormatFilter=</a>

These SEC filings are only available from 2010 when Tesla Motors was offered on NASDAQ for the first time. This creates issues because the Tesla Roadster was released for sale in 2008, therefore alternative sources of information were required for 2008-2010. This information was obtained from media reports that were released at the time. Many of these reports followed the market introduction of the Tesla Roadster from 2008 onwards. At the time this was an exciting event so media coverage was substantial. Some information was also obtained from Tesla's own press releases, along with presentations and interviews by the company CEO. These sources of information were used to obtain sales figures of the Tesla Roadster in the years before 2010. The reported sales figures can be confirmed using later reports and in the 2012 Form 10K Tesla Motors report the final sales numbers for the Roadster.

The next chapter in this thesis concentrates on the development of new infrastructure. The first part of chapter 7 presents an overview of each generation of mobile phone networks, from 0G to 4G networks. This section is descriptive and is intended to build context. It is also an example of how unrecorded historical data can

be inferred. The data in this section is taken from a small number of academic publications, media reports, patent filings, blogs and mobile phone company websites. The most important result in this study is the data showing the pre-development of infrastructure. This quantitative data shows how mobile phone infrastructure was developed, prior to market entry occurring. This data is partly taken from GSMA (Groupe Speciale Mobile Association) data, which measures the Global Coverage of GSM networks (GSMA, 2012). However, the data is not complete, for some years before 1999 no data from GSMA is available, for these years Nokia Siemens data was used (Nokia Siemens Networks, 2011). This Nokia Siemens data counts the number of networks in operation from 1991 to 2013. Therefore for the years which GSMA data was not available it was known how many networks existed, for the years with GSMA data Nokia Siemens data was also available. This means for the years 1999-2013 it is possible to calculate what percentage population coverage results from a given number of networks. Therefore for the years prior to 1999 the average population coverage per network was used to extrapolate the data backwards. Both sets of data only account for GSM networks and not more advanced 3G or 4G networks. GSM networks are by far the most widespread globally accounting for 90% population coverage. The coverage of more recent 3G and 4G networks are not measured here, these networks did not help with the initial market entry of mobile phones, rather they support the increasing functionality of the mobile phone as it goes through continual product development.

### **4.3 Questionnaire Survey Methods**

The second method to be used in this thesis is one of questionnaire surveys. This thesis contains the results of two questionnaire surveys, one with a larger sample of 340 respondents (Chapter 8 and 9) and another smaller sample of 30 respondents (Chapter 12). The subject of the first questionnaire survey is BEVs and the second is FCVs. These surveys can be seen in the appendices, with appendix 1 showing the online questionnaire survey and appendix 2 showing the smaller FCV survey. The questionnaire surveys are used to meet part of the second and third aims of this thesis. Questionnaire surveys are useful as they allow a relatively large sample to be gathered by the researcher. The benefit of this is that results can be tested using statistical analysis (Bryman and Bell, 2015). Questionnaire surveys also allow a large number of topics to be covered, because questions can be quick to complete, this means that in a relatively short period of time a large sample covering a variety of topics can be gathered. Online questionnaire surveys require less input time from the researcher during data collection in comparison to verbally administered questionnaire surveys, again allowing more data to be collected. Questionnaire survey data is also objective rather than subjective in nature (Steckler et al., 1992), meaning it is a factual and reliable source of information.

Quantitative research does have shortcomings though; questionnaire surveys are inherently affected by sample bias. Due to the way in which respondents were recruited in this study, some members of the target population could be missed. For example due to the questionnaire survey being administered over the Internet people who do not have access to this would not have been able to participate in the study.

The sample, though, is still relevant for this study and even though certain people may have been more willing to respond to the questionnaire survey, these people are still early adopters, as will be shown later. Clearly, questionnaire survey answers are self reported and this can also result in respondent's answers not being representative of their actual behaviour. In any questionnaire survey, and also interviews, there is the risk of acquiescence bias, where respondents have a greater tendency to agree with questions (Kam and Zhou, 2014; Watson, 1992). This can be mitigated by neutrally wording questions or by having both positively and negatively worded questions. The presence of more than 2 response options (i.e. yes and no) by using a Likert scale can prevent this (Goldsmith and Hofacker, 1991). Further, there is the possibility of a bias due to respondents changing the way in which they answer questions simply due to the fact that they are taking part in a study. This is known as 'demand characteristics' (Reese et al., 2013). Respondents may do this unintentionally or may do it to influence the results by either answering in a disproportionately positive or negative way depending on their motivations. This is known as extreme responding. Finally there is also the risk of social desirability bias; this is where respondents answer in a manner that they deem to be the socially acceptable norm. This is more of a problem in a questionnaire survey where follow-up questions cannot be asked, in in-depth interviews, follow-up questions can be asked to confirm the validity of interviewee responses (Furnham, 1986). The respondents answer both of these surveys unaided rather than aided. This allows responses to be more natural and removes any influence the researcher could have on the interviewee, which can result in more accurate findings. All of these shortcomings are widely known and cited, and are deemed to be an acceptable risk

in the pursuit of statistically valid quantitative data, providing measures are taken to reduce the chances of these biases from occurring. Furthermore the thesis uses both questionnaire surveys and qualitative in-depth interviews, and the use of both of these is known to produce more reliable and valid data (Steckler et al., 1992).

#### **4.3.1 Online Questionnaire Survey**

Between July and December 2014, 340 fully completed surveys were collected. This data forms the basis of the results in chapter 8 and 9. By the end of 2014 there were 665,000 BEVs worldwide with 39% (275,000) of these being in the United States. For this reason, the questionnaire was targeted towards North American owners of BEVs. The way in which owners were recruited to participate in the questionnaire was via online forums. The following forums were identified and used:

- [Forums.teslamotors.com](https://forums.teslamotors.com), the official Tesla forum.
- [Reddit.com/r/teslamotors](https://reddit.com/r/teslamotors), an online forum with a sub-area for Tesla enthusiasts.
- [Reddit.com/r/electric vehicles](https://reddit.com/r/electricvehicles), an online forum with a sub-area for electric vehicle enthusiasts.
- Nissan and Infiniti Car Owners, a forum for Nissan and Infiniti owners, including the Nissan Leaf.
- Leaf Talk, a Nissan Leaf owner forum.
- Speak EV, a forum for owners of any electric vehicle.

Three main topics from the questionnaire survey are presented in this thesis. The first gathered socio-economic data, the second psychographic information, the final section asked for information on respondents' opinions of their vehicle's attributes, and also asked them about their future BEV purchase intentions. The way in which these questions were formulated is explained below.

Socio-economic data was recorded to understand the socio-economic profile of adopters. Questions were developed based on the existing literature, outlined in the review, which makes statements about early adopters gender, age, income, level of education and the number of cars in the household; these 5 attributes were used to understand respondent's socio-economic profile

Rogers' theory (Rogers, 2003) makes some generalisations about early adopters' psychographic profile. These help towards identifying the types of people that may be adopters of new technologies in general. These generalisations along with findings from existing BEV literature were used to develop 20 questions, which measure respondent's psychographic profile. This allows a more quantitative method in deciding if low-end and high-end adopters are significantly different from one another. All 20 questions can be seen in Table 8.6.

Prior to creating a list of questions to ask respondents, the potential benefits and shortcomings of BEVs needed to be ascertained. This was partially taken from the case study results, but also a number of pilot interviews with UK BEV adopters, in total 5. They were asked why they chose to adopt a BEV and what the benefits of ownership are. The following 10 attributes measured in this survey emerged as the

perceived benefits or shortcomings of the vehicles and reasons for adoption of a BEV:

1. Brand
2. Vehicle Image/ Looks
3. Purchase Price
4. Vehicle Range
5. Time to Refuel
6. Vehicle Performance
7. Fuel Economy
8. Environmental Impacts
9. Life Style Fit
10. Running Costs

Respondents were asked to compare their vehicle to an ICEV in order to ascertain in what manner the vehicles are perceived as worse, similar and superior on a 5 point Likert scale (Far Superior, Slightly Superior, Similar, Slightly Worse, Far Worse). This is known as a semantic differential scale (Bryman and Bell, 2015). After respondents were asked about their vehicle attribute opinions they were asked two questions that measured if they would continue with BEV adoption in the future. The first measured the likelihood of continual ownership of any BEV, the second measured any brand loyalty to the current BEV that they own. These questions measure consumer perceptions and not the actual performance of the vehicles. As is discussed in (Crawford and Benedetto, 2011), consumer perceptions are more important than actual product performance. Therefore the results reported here may not necessarily be representative of the actual attributes of a BEV, but they are representative of how early adopters view these attributes.

The data collected in the 340 survey responses contains two groups of BEV adopters. The first are owners of Tesla BEV's (high-end adopters, n=155). The second group are low-end adopters (n=185). Chapter 9 explores what price premium early these adopters have paid for their current BEV compared to an ICEV. Of the 340 responses received, it was only possible to calculate the difference in price paid for a BEV for 288 respondents. This was due to a number of reasons. The response box for the car owned previously was not mandatory, resulting in not all users filling it out. Additionally, some respondent's previous vehicles were no longer in production so their present day purchase price could not be calculated. Further to this, some respondents owned BEVs that are no longer in production, for example the Tesla Roadster.

In chapter 8 a number of statistical techniques are used to further investigate the data. In total three are used, these being the t-test, chi-square and multiple linear regression. The way in which these are used is explained later in this chapter.

In order to calculate the difference in purchase price for adopters BEV compared to the vehicle they previously owned two sets of data were needed. The first set of data is the price of the BEV that the respondent has bought. Secondly, the price they would usually pay for an ICEV was needed. This data was more challenging to gather. In the online questionnaire respondents recorded the make and model of the vehicle they had owned prior to buying the BEV. It would not be correct to compare the purchase price of this vehicle to the price of the respondent's current BEV. Many of the vehicles were purchased a number of years back. This would mean that the gap in price paid could be exaggerated due to price increases owing to inflation. The data would also not be uniform as some owner's previous vehicle was purchased in



1995, whilst others were purchased more recently. Therefore the data had to be made uniform. In order to do this, the present day values of the respondent's previous cars were used. For example it is assumed that the prior owner of a 1995 VW Golf would have purchased a present day VW Golf if they had not adopted a BEV. This means the results reported in this investigation are more meaningful in the way of price comparisons. The actual difference in price paid reported here is therefore the difference between the price of the early adopter's BEV and the present day price of an ICEV that they had previously owned. All data is shown in US\$ and purchase prices are taken from the Manufactures Suggested Retail Price (MSRP).

The prices reported in this chapter are stated in absence of any government grants. This is due to the extremely complex situation regarding incentives for BEVs. In the USA incentives differ between states, for example, in California, a US\$2,500 state rebate is available in addition to the US\$7,500 federal tax credit. Further to this some counties in California offer additional incentives, known as local incentives. These can be an additional US\$1,000 (DriveClean.ca.gov, 2016). Even without taking into account any government grants in calculating the price premium paid for a BEV, this study is more accurate than previous ones, by being the first study to use more reliable behavioural data instead of attitudinal data in calculating the premium paid for a BEV.

### **4.3.2 Verbally Administered Questionnaire Survey**

Chapter 12 uses results from a different questionnaire survey all together with a much smaller sample size (n=30). The layout of the questions, though, was the same; in particular the same vehicle attributes and Likert scale are used as in the

online questionnaire survey, meaning it is possible to make comparisons between both data sets. Respondents were recruited for this study at the Low Carbon Vehicles 2015 event in Millbrook, UK, and the survey was verbally administered. The event is an annual showcase of low emission vehicles, including advanced ICEVs, HEVs, PHEV, BEVs and FCVs. In 2015 there were 2852 visitors to the event and 103 low carbon vehicles were on display. Visitors to the event have the opportunity to take the majority of the vehicles on display out on test drives. The test drive route is at the Millbrook Proving Ground in Bedfordshire, UK. The route involves a drive around the 5km Alpine Handling Circuit and the 3.2km High Speed Bowl. This allows drivers to experience braking, acceleration, road handling, and the top speed of vehicles. This event was selected as it would attract persons who have interest in BEVs and FCVs therefore may be potential early adopters. This means that the data will not be representative of the general population's opinions of FCVs; but it is still indicative of the opinions that early adopters have of FCVs. This is important because, by definition, early adopters will be the first people to purchase the vehicles. Furthermore, as consumers are able to drive both BEVs and FCVs on a varied driving route, they are able to make full comparisons between the vehicles in a way not previously seen within the literature. At the event, 81 attendees drove the FCVs and of these 30 took part in the study. What makes this sample unique is that most respondents in this study have experience of both a FCV and a BEV, with 86.7% of them having driven both types of vehicle. Therefore they were able to make direct comparisons between FCVs, BEVs, and ICEVs. After respondents had taken part in the trial drive of the FCVs they were asked a series of questions relating to how they perceived the vehicles. Questions first measured how they saw the vehicles

in comparison with ICEVs. Then respondents were asked to compare FCVs with BEVs. Finally respondents were asked qualitative questions exploring what they liked and disliked about the FCV they drove.

Similar to Chapter 8 some statistical analysis is done in this chapter. In this chapter the T-test is used to compare the means between three data sets. The means for the sample gathered in this chapter are in fact compared to the data presented in chapter 8. This means that three sets of data are being compared, these being the low-end BEV sample, high-end BEV sample and the FCV trial sample from this chapter. Indeed, the F-test could be used to compare differences in the means between all three samples. However, in this case the differences in the means between all three samples are not of interest. The interest here is the differences between the FCV trial sample and the low-end BEV sample and then the FCV trial sample with the high-end BEV sample. Using the F-test to investigate these relationships would not produce meaningful results as the significant differences between the low and high-end samples explored in Chapter 8 would influence the results. For this reason the T-test is used, the way in which this is calculated is explained below.

### **4.3.3 Questionnaire Survey Data Analysis**

In order to analyse the data, three statistical techniques are used. In order to compare means between samples that gather ordinal data, the T-test is used. In order to compare statistical differences between samples that do not use an ordinal scale and use a nominal scale Chi-square is used. Finally linear regression is used to find out whether and which of a number of hypothetical independent variables have a

significant impact on the dependent variable. The way in which these techniques are used is summarised in Table 4.3.

Table 4.3: Summary of the statistical techniques used for the questionnaire survey, what they are used for and the reason they were selected.

Statistical Test	Use	Reason
<b>T-test</b>	Comparing psychographic and vehicle attribute data for each adopter group	Comparison of Likert scale or ordinal scale questions
<b>Chi Square</b>	Comparing socio-economic data for each adopter group	Comparison of questions without Likert scale
<b>Multiple Regression</b>	Exploring the relationship between vehicle attribute and future adoption data	Comparing multiple independent variables to one dependent variable

In order to identify the differences between high and low-end adopters in the online questionnaire survey the T-test is used. The T-test is also used to compare the results from the LCV questionnaire survey and the online questionnaire survey, as was described above. The T-test compares samples in order to understand if there is a statistically significant difference in their means. In this case it is used to compare questions that use a Likert scale. In order to reject the null hypothesis the standard 5% confidence level is used, this means a significance value ( $p$ ) of 0.05 or below is needed. If a null hypothesis is rejected this means that there is a significant difference between the two sample populations. Independent samples T-test is calculated using the following:

$$T = \frac{X_1 - X_2}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}}$$

$T$  = obtained  $T$  value

$X_1$  and  $X_2$  = means for the two groups

$s_1^2$  and  $s_2^2$ = variances of the two groups

$n_1$  and  $n_2$ = number of respondents in each of the two groups

Chi-Square is used to assess differences in the socio-economic data. Chi-square is used here, rather than the T-test, because the data is nominal data. The usual 0.05 significance is used to reject the null hypothesis. Chi-square goodness of fit is calculated using the following:

$$X^2 = \sum \frac{(O - E)^2}{E}$$

O= observed value

E= expected value

In order to understand the data further, multiple linear regression models are used. In this case it is used to understand how early adopters views of the different attributes of their vehicles may relate to their willingness to continue with BEV ownership. This therefore works toward understanding which vehicle attributes are the biggest influence on future purchase intentions. The first stage of analysis is deciding whether the regression model has explanatory power. This is done by testing ANOVA (Analysis of Variance), which is rejected at the usual 0.05 level. In this case the null hypothesis for each variable is rejected at a significance of 0.1. This is less stringent than 0.05. This study focuses on early adopters and investigates the behaviours and opinions, therefore is a study within the field of social science. Within this field, due to

the larger number of variables, it is permissible to use this less stringent level of significance compared to natural sciences. The variables that are rejected at a significance of 0.1 are then further tested. This time only the values that are significant at a level less than 0.1 are retained in the regression model. For this final regression the null hypothesis is again set at 0.1. The variables less than 0.1 will be a significant influence on the dependent variable and the model is therefore a good predictor of future vehicle purchase intentions. This method of stepwise regression analysis is known as the backward elimination method. Multiple regression derives from simple regression, which is calculated using the formula below:

$$Y = a + bX$$

$$a = \frac{\sum Y - b \sum X}{N}$$

$$b = \frac{N \sum XY - (\sum X)(\sum Y)}{N \sum X^2 - (\sum X)^2}$$

Where,

Y= the dependent variable

X= is the independent variable

b= the slope of the regression line

a= the intercept

Multiple regression, which is used in this study, is a more advanced technique and is used to predict the value of a dependent variable based on more than one independent variable. The equation for multiple regression is shown below.

$$Y = a + b_1(X1) + b_2(X2) + b_3(X3) + \dots + b_K(XK)$$

Where,

Y= the dependent variable

X= are the independent variables

b= the slope of the line

a= the intercept

Within all of the results chapters that use these techniques the level of significance in the data tables is noted by using the standard system of significance starts where  $\leq 0.001$  is noted with \*\*\*,  $\leq 0.01$  with \*\* and  $\leq 0.05$  with \*. Even though the level of  $\leq 0.1$  is used for linear regression this is not noted with a significance star, as this is not the standard within statistical analysis.

#### **4.4 Qualitative In-depth Interviews**

In this thesis a questionnaire survey is used prior to qualitative in-depth interviews. This is contrary to the norm where in-depth interviews often precede a questionnaire survey. This is usually done so that a questionnaire can be constructed based on the insights gained from in-depth interviews (Bryman and Bell, 2015; Steckler et al., 1992). In this thesis, though, the qualitative method is used to explore results from the questionnaire survey in more depth. The questionnaire survey revealed two different groups of early adopters, with high-end BEV adopters being found to be more representative of early adopters; the interviews therefore concentrate on just this group. The results of these in-depth interviews are the subject of chapter 10 and

11. Each chapter corresponds to a different part of the interviews, with chapter 10 examining BEV adoption and chapter 11 examining attitudes toward FCVs.

Between the months of March and June 2015 interviews took place with 39 owners of Tesla BEVs. Prior to the study it was expected that an appropriate number of interviews would be 30. At this point it was expected that theoretical saturation would occur and no new themes or topics would emerge. Therefore the sample of 39 early adopters is a sufficient sample size, and is similar to previous qualitative studies (Caperello et al., 2013; Graham-Rowe et al., 2012; Kurani et al., 1996). Interviewees were recruited via word of mouth and through electric vehicle clubs. Once an interviewee had been interviewed they were asked if they knew any other Tesla owners and if they would be willing to forward a participant information letter to them. This same letter was sent to a number of electric vehicle clubs, which circulated it around their members. This method is commonly referred to as snowball sampling (Bryman and Bell, 2015), as over time the number of interviews grows in an almost exponential fashion. This resulted in 39 interviews, all in the San Francisco Bay and the Sacramento Valley areas in Northern California. Interviews typically lasted 1 hour, with some lasting up to 1 hour 30 minutes and some only lasting 30 minutes due to time constraints on the interview day. For this reason some of the results are based on 36 of the interviews as 3 interviewees were not asked a particular question. This is indicated where the data is presented. The majority of the data is based on all 39 interviews. The interview location was selected as Northern California due to the high number of BEVs registered there. San Francisco for example has the highest proportion of new vehicles that are electric in the United States, with 6% of new



vehicles being BEVs or PHEVs (Lutsey et al., 2015). Therefore it was easier to access interviewees in this area as opposed to areas with a low BEV market share.

Interviews, along with questionnaire surveys, are not without shortcomings. The use of both of these methods in the same study, though, means that the shortcomings are overcome. Interviews do not typically gather a large statistically representative sample; this is however achieved by the questionnaire survey. Instead, interviews gather in-depth, detailed and rich information allowing topics that a questionnaire survey might miss to be uncovered. In-depth interviews also allow follow-up questions to be asked and this can reduce social desirability bias as the interviewer can detect this by asking questions that can conform or refute what the interviewee is saying. This method can also remove any acquiescence bias by wording questions neutrally, not providing any answer cues too early, allowing interviewees time to consider their responses and also by asking follow up questions (Bryman and Bell, 2015).

All interviews were audio recorded and after the interviews took place were fully transcribed by the interviewer. The way in which interviews were analysed is through the grounded theory approach. Grounded theory analysis is described in (Bryman and Bell, 2015). Throughout the data collection process, research notes are kept, and some limited data from the interviews is recorded. This allows researchers to keep track of trends and be aware of when theoretical saturation has occurred. After all interviews were complete they were transcribed and imported into the qualitative analysis program NVivo. All transcripts were reviewed and common themes were analytically coded using nodes. After all transcripts had been analysed it is possible to group different nodes into categories with other nodes that are related to the same

issue. The codes and categories are developed from the data and not by any pre-existing conceptualisations. This allows the discovery of basic social processes in the data. The advantage of using this approach is that it allows underlying issues to emerge without any preconceptions influencing the researcher, allowing themes to arise on their own and not due to any expectancy bias or confirmation bias. This method has previously been used in a qualitative study involving 40 consumers who had taken part in a Hybrid Electric Vehicle (HEVs) trial (Graham-Rowe et al., 2012). In order to support the validity of the data presented in this chapter quotes are presented along with the interviewee's reference number. This prevents any scepticism emerging from the reader and makes the results more transparent.

#### **4.4.1 A qualitative investigation into high-end battery electric vehicle adopters**

Chapter 10 presents data from the first part of the in-depth interviews. This half of the interviews only explored BEVs and the data is useful in supporting some of the findings from the questionnaire survey but also in exploring some of those findings in more detail and additionally uncovering new topics that the questionnaire survey did not uncover. The interviewees' education, careers, current employment, household vehicles and other topics related to their background were explored. This allowed an understanding of the interviewees' socio-economic profile. Interviewees were then asked about their reasons for purchasing their current BEV in order to understand the motivational factors for adoption. Then the benefits of ownership were explored in order to understand the advantages of owning a high-end BEV. Exploring both reasons for purchase and benefits of owning a BEV is important, as there may be

differences between answers to each question. Motivational factors are something that consumers will consider in a pre-purchase situation, these factors result in adoption. Benefits of ownership are what consumers experience post-purchase, they therefore are important in the confirmation stage and can influence future purchases and ideally cause repeat purchases.

#### **4.4.2 A qualitative investigation into early adopters attitudes toward fuel cell vehicles**

The results in chapter 11 are taken from the second part of those interviews that explored the interviewees attitudes toward FCVs. Asking this sample of BEV adopters about FCVs is especially useful, and this is the only sample of this kind within the literature. The sample does not have experience with FCVs, but the interviewees are early adopters of high-end BEVs, meaning they have adopted a zero emission automotive innovation that cost more than ICEVs. These are shared traits with FCVs. This means that the sample will be similar to the people who will be the first to adopt FCVs and this makes the perceptions more insightful compared to those of the general public.

Interviewees were asked if they were aware of FCVs, and then in order to ascertain what level of knowledge the interviewees had of FCVs they were asked what they knew about the vehicles. Then they were asked what the barriers to them adopting a FCV would be. Finally interviewees were asked two questions which related to specific attributes of FCVs. Firstly, what range they currently get from their BEV, if they would desire more range, and what range they would desire. This was in order to understand if there is consumer demand for the range of a FCV. Secondly

consumers were asked if they would want their vehicle to be able to provide vehicle-to-home power, in the event of a grid power outage. They were first asked if they would desire the feature, then they were asked how much they would be willing to pay for such a feature.

## **4.5 Summary**

This chapter gives an overview of the three different methods used to meet the aims of the thesis. The use of historical case studies and the information that resulted from this method builds a foundation of knowledge for this thesis. The online questionnaire survey with 340 respondents then builds on this foundation and provides more insights. And finally the in-depth qualitative interviews, with 39 interviewees, aid in clarifying the information uncovered by the questionnaire survey, but they also bring new findings to light. The final, verbally administered questionnaire survey, with 30 respondents, is smaller than the first, but still brings new insights. Combining both quantitative and qualitative research methods is important in this thesis, and indeed any social study. Using a mixed methods approach means that the strengths of each method can be exploited and the weaknesses can be offset. Having two or more methods exploring the same topic allows 'triangulation', where the results of two studies are compared in order to increase confidence in findings. In this thesis the 340 questionnaire survey responses can be corroborated with findings from the 39 in-depth interviews. Results are more robust and reliable, and it also means that all issues associated with the aims and objectives are sufficiently met.

# CHAPTER 5

Lessons from historical disruptive  
innovations

# Chapter 5    Lessons from historical disruptive innovations<sup>1</sup>

## 5.1    Introduction

This chapter presents findings from 7 historical case studies of disruptive innovations that achieved successful market entry. The hope is that these examples will provide some insights into how FCVs, or indeed any other automotive innovations might enter the automotive sector. This chapter therefore presents findings from historical innovations and also a brief exploration of the BEV. These innovations were all introduced to a market that had an incumbent product that dominated the mass market. They were all introduced at higher prices, had little infrastructure to support them prior to their full development and in some cases were initially technologically inferior. All of these things are also true for FCVs, which are more expensive than ICEVs, have less infrastructure, and they have not benefited from over 100 years of development like ICEVs have. Therefore it is hoped that FCVs may be able to take lessons from these historical examples.

### 5.1.1 Disruptive Innovations

The investment of private money in technological innovation is driven by the expectation of successful market penetration. This decision to invest is less risky when innovations represent gradual improvement of existing technologies, for example efficiency improvements in ICEs. The term disruptive innovation is used to describe the opposite case, i.e. innovations that are so different that their

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<sup>1</sup> The results in this chapter are based on the publication Hardman, S., Steinberger-Wilckens, R. & van der Horst, D., 2013. **Disruptive innovations: The case for hydrogen fuel cells and battery electric vehicles.** *International Journal of Hydrogen Energy*, 38(35)

establishment in the market causes a disruption to the pre-existing system. The existing literature on disruptive innovations provides us with historic case studies of successful market entry by new technologies, but this in itself is insufficient to understand the chances of success for nascent technologies. This chapter sets out to bring greater clarity to the characteristics of disruptive innovation in a way that informs the debate on the viability of emerging technologies. Whilst existing definitions are based on technologies that were successful, this paper proposes a three-part criteria to define candidate disruptive innovations: disruption should relate to manufacturers and/or infrastructure (the two often being inter-related), whilst innovation will also alter the way in which consumers interact with the technology. The review of 7 historical case studies of successful disruptive innovations reveals 8 common characteristics.

The purpose of this chapter is to understand how innovations successfully achieve market entry and to determine what defines candidate disruptive innovations and what characteristics lead to them displacing incumbent technologies. It will also review an example of a candidate disruptive innovation that is currently in the niche market penetration phase, the BEV.

An integral aspect of understanding disruptive innovations is the need for a clear definition. An improved definition is proposed after reviewing the findings of the historical successful disruptive innovations and the BEV. These findings allow fundamental characteristics of successful disruptive innovations to be identified. These fundamental characteristics are then used to form criteria, which can be used to identify if a technology is, or will be a candidate disruptive innovation. These criteria will allow us to explicitly define what we mean by disruptive innovation for the

first time. Finally these findings are applied to FCVs. There is a need to confirm that FCVs are a disruptive innovation, because if they are, they will face specific challenges upon market entry.

There are many examples of successful disruptive innovations. In this chapter seven case studies of past successful disruptive innovations are undertaken in order to improve the understanding of how disruptive innovations enter markets. A clear definition of 'disruptiveness' is still lacking at this point. This will be offered later in this chapter. Provisionally the analysis of the historical case studies builds on the assumption that a disruptive innovation will cause major turmoil to the existing market. The case studies reviewed are:

1. The introduction of the quartz watch in the 1970s which lead to the demise of the Swiss watch industry and mechanical watches (Markides, 2006; Tajeddini and Trueman, 2008; Young, 1999).
2. The introduction of the mass produced automobile which eventually served as a replacement to horse drawn carriages (Geels, 2005; Melaina, 2007).
3. The introduction of digital cameras in the 1990s which eventually took the mass market share in the photography sector away from film cameras and the market leader Kodak (Danneels, 2004; Lucas and Goh, 2009).
4. The introduction of steam ships which eventually replaced sail driven ships (Geels, 2005).
5. The introduction of hydraulic excavators as an alternative to conventional cable driven machines (Bower and Christensen, 1995; Danneels, 2004).



6. The recent introduction of eReaders (and tablets such as the iPad) that have already had an impact on book sales (and possibly laptop sales) and are predicted to reduce sales further.
7. The introduction of mp3 players, especially the iPod in 2001, which saw the replacement of personal CD and tape players (Harrison et al., 2005; Islam and Ozcan, 2012).

## **5.2 Common Characteristics of Disruptive Innovations**

After reviewing the above examples of innovations some common characteristics of successful disruptive innovations have been identified. These observations are outlined below.

1. The threat of the new technology is often not recognised by existing market leaders.

Even when the threat is recognised, no significant action is taken by the incumbent companies to develop the disruptive innovation themselves. The action usually taken is explained by the 'sailing ship' effect where incumbent technologies seek to maintain their market share via cost reductions or incremental technological improvements. These efforts are helpless and the organisations that fail to adopt will be negatively impacted. Examples of this include Kodak failing to adopt the digital camera in sufficient time for them to remain a market leading company, HMV failing to adopt to music and film downloads and Bucyrus-Eire failing to adopt hydraulic excavators. Many companies disappear completely after failing to adapt disruptive innovations. Some companies do recover, though. The Swiss watch industry was

almost wiped out by quartz watches in the period known as the 'Quartz Crisis'. Swiss watches accounted for 95% of the watch industry revenue prior to the introduction of Quartz watches (Tajeddini and Trueman, 2008). Exports of Swiss watches fell from 40 million units in 1973 to 3 million units in 1983 (Young, 1999). But now the Swiss watch industry has recovered. Partly this is due to the industry adopting quartz movements, which dramatically reduced the price of Swiss watches. It is also because the industry has been able to fill high value watch niches across the world. In 2011 the Swiss watch industry achieved revenue of £13 billion (FHS, 2011). It is clear that all disruptive innovations, if successful, will dramatically change the face of the markets that they enter.

2. Disruptive innovations are initially more expensive than the incumbent technologies.

This is known as high-end encroachment. Low end encroachment is also possible, but high end encroachment seen in the examples investigated here has a quicker and more dramatic effect on the market (Schmidt and Druehl, 2008). The successful disruptive innovations reviewed are far more expensive upon market entry. Table 5.1 shows how disruptive innovations are 4-30 times more expensive than incumbent technologies at the time of market entry. The high prices are usually due to complex manufacturing processes, the new technologies requiring high cost materials, not yet benefiting from economies of scale, and the early attempts at retrieving development costs. After the technologies enter niche markets unit sales increase and costs will fall due to manufacturing optimisation and economies of scale. This occurred when automobiles began disrupting the horse drawn carriage market. Automobiles did not become significantly disruptive until mass production had been established and

prices were more affordable to a larger number of consumers. The costs of successful disruptive innovations will eventually fall to a price that is competitive to the incumbent technologies.

Table 5.1: Cost comparison between the incumbent technology and the successful disruptive innovation. Costs are taken from the years show (Apple, 2010; Duggen, 2004; Geels, 2005; Hamilton, 1970; IEEE GHN, 2004; The Old Radleian, 2012; Wired, 2008).

Market Area	Incumbent Technology	Price	Disruptive innovation	Price	Year
<b>Photography</b>	Film Cameras	US\$135	Digital Cameras	US\$995	1990
<b>Road Transport</b>	Horse Drawn Carriages	US\$20	Mass Produced Automobile	US\$850	1908
<b>Mining/Construction</b>	Cable Excavators	No Data Available	Hydraulic Excavators	No Data Available	
<b>Watches</b>	Mechanical Watches	US\$30- US\$500	Quartz Watches	US\$1,250	1969
<b>Boats</b>	Sailing Ships	£16,500	Steam Ships	£117,000	1845
<b>Reading</b>	Books	US\$5-20	eReaders	US\$400	2011
<b>Personal Music</b>	Personal CD Player	US\$80	iPod	US\$400	2001

3. The quality of the disruptive innovation initially is worse than the quality of the technologies they seek to replace.

The technologies investigated here all initially had shortcomings in some key areas compared to the incumbent technologies. These include; reliability, build quality, operating costs, purchase price, speed and vehicle range. Table 5.2 summarises the disadvantages and advantages of the new technologies compared to the incumbent technologies they were disruptive to. Hydraulic excavators had a shorter reach, smaller bucket size and lower weight limit than conventional cable driven excavators. This meant that the amount of earth they could move was lower than the incumbents.

Early machines could only haul 0.25 cubic meters and could only reach 6 feet. But after niche market penetration had begun hydraulic excavator bucket capacity increased 15% year on year between 1948 and 1974 (Bower and Christensen, 1995; Danneels, 2004). The early hydraulic systems proved to be unreliable and maintenance infrastructure was under-developed. The reliability of hydraulic excavators did eventually surpass the reliability of cable driven excavators due to the systems having fewer moving parts, and because maintenance infrastructure increased along with market penetration.

#### 4. The technologies have some advantages to consumers.

These advantages can be hard to anticipate and define beyond a technology's noticeable functional advantage. Convenience, running costs, accuracy and speed will only be advantageous in a technology if the consumer desires them. Some advantages, though, can arise unexpectedly, this mainly comes in the form of emotional values such as prestige and lifestyle values. If desirable values can be purposely designed into a technology then market penetration may become far easier. The iPod had advantages of user friendliness, mass storage and convenience over portable CD players but consumers especially viewed it as 'cool', giving it social prestige. This allowed it to expand from the niche into mass markets with an impressive trajectory. The iPod was launched in 2001, by June 2003 one million had been sold (Apple, 2010).

Table 5.2: The advantages and disadvantages of the successful disruptive innovations compared to the incumbent innovations that they replaced, at the time of the market introduction (Bower and Christensen, 1995; Danneels, 2004; FHS, 2011; Geels, 2005; Harrison et al., 2005; Islam and Ozcan, 2012; Lucas and Goh, 2009; Markides, 2006; Tajeddini and Trueman, 2008; Young, 1999).

Technology	Advantages	Disadvantages
<b>Digital Cameras</b>	Convenience, No Film Required	Price, Picture Quality, Speed
<b>Mass Produced Automobile</b>	Prestige, Recreational Uses, Thrill seeking	Price, Speed, Reliability, Lack of Infrastructure
<b>Hydraulic Excavators</b>	Quicker operation and more mobile, Convenience, Cheaper Production, Fewer moving parts	Cost, Shorter Reach, Smaller Bucket, Lighter Load Limit, Lack of maintenance infrastructure
<b>Quartz Watches</b>	Accuracy, Prestige, Reduced complexity	Price, Poor Quality
<b>Steam Ships</b>	Larger size, Bigger capacity, Not restricted by wind speed	Price, Fuel costs, Speed
<b>eBooks</b>	Convenience, Cheaper book price, Environmentally Friendly?	Price, Legibility, Reliability
<b>iPod</b>	User Friendly, Mass Storage (1000 songs), Convenience, Prestige,	Price, Reliability, Poor Battery Life

5. The disruptive innovations will fill niches markets first, here they spread to other niches and eventually reach the mass market.

Disruptive innovations are at their most disruptive to incumbent technologies when they reach the mass-market level, but to reach there they must first occupy the niches where they are less disruptive. Hydraulic excavators were no use to the mining, excavation or sewage construction industries that represented the mass

markets for excavators. These industries had no interest in the short reaches and small capacity buckets. Early hydraulic machines were introduced into the residential construction industry for digging small areas, which were previously dug by hand. This niche market was in growth thanks to the boom in residential construction post WWII in the USA. Upon filling this niche, revenue generation from increased unit sales helped with technology development. This led to hydraulic excavators eventually being attractive to the construction and mining industries; eventually hydraulic machines became comparable to cable driven machines. When performance was comparable, the increased reliability of hydraulic machines saw them outcompete incumbent cable driven devices. The easier operation also gave them advantages because they could penetrate vertically into the earth, something that conventional dragline cable machines could not do.

6. The incumbent technology is never wiped out all together; it in turn becomes the technology for niche markets.

Many incumbent technologies will eventually end up in niche markets, similar to where they began. The technologies will still have characteristics that are desirable to some individuals. 35mm film cameras are still used today in many niche applications. Many professional photographers and artists use film cameras to produce specialist photographs. Disposable film cameras are also used for their low costs. Today horse drawn carriages and horses are used for recreational purposes in the first world and they are still used for transportation in the 3rd world and by minority communities such as travellers and Amish people. Cable driven excavators are still used in mining applications; the biggest machines are still far larger than any hydraulic excavator. Sail driven ships are still used for recreational purposes and for racing. There is also

a renewed interest in hybrid sail driven freight ships to help reduce fuel costs and increase efficiency (Skysail, 2012).

#### 7. Many innovations require investments into new infrastructure

Many new technologies require entirely new infrastructure to support their usage and market entry. Often prior to the introduction of the new technology no infrastructure is in place to support its consumer adoption. Prior to the iPod being introduced, music download websites, especially iTunes, did not exist, and without these in place the iPod would not have been successful. Some innovations are able to achieve initial market entry by using some existing infrastructure. Early adopters of the mass produced automotive for example were able to utilise existing petroleum distribution channels. These already existed for applications such as machinery, lighting and farm equipment (Geels, 2005; Melaina, 2007). This meant that there was a usable supply network already in place. However in order for the vehicles to spread in wider numbers new infrastructure, in the form of purpose built filling stations was required.

#### 8. Socio-technical systems are always evolving.

Socio-technical and socio-economic systems are complex and are always changing at different rates. Incumbent and innovative ideas are continually competing for market shares. No incumbent will remain in the mass market indefinitely. The incumbent technology was at a time the disruptive innovation, which entered a niche and eventually penetrated mass market. The incumbent technology will be replaced by a new technology that will eventually occupy the mass market and become the incumbent. As a result of the fast paced nature of markets many companies struggle to keep pace with innovations and will die out. Often companies will have to make

decisions that are counter intuitive. Niche markets will look financially unappealing to companies occupying mass markets and they will dismiss the niche due to low unit volumes and hence low revenue generation. But if market leaders do not enter the niche in the early stages of the technology they will fall behind more innovative companies. An example of this is IBM who for years dominated the mainframe market but did not manage to capitalise on the mini computer market. The Swiss watch industry also initially failed to introduce Swiss made quartz watches and left the way for Asian companies to dominate the market. This is despite the fact that quartz was a Swiss invention.

### **5.3 The Case for Battery Electric Vehicles**

The introduction of BEVs is a disruption we are able to witness first hand. This example is especially useful because it is hoped that FCVs will be able to take a market share of the automotive sector similar to what battery BEVs are pushing for today.

In the automotive sector ICEVs are the incumbents. It is inevitable that an innovation will displace them. BEVs are a disruptive innovation (see section 5.4 and Pilkington and Dyerson, 2004; Pilkington et al., 2002). New companies produce BEVs and their components, they require different infrastructure and they provide additional service over ICE vehicles. After investigating the range of BEVs on sale today it is clear that there are two different successful market entry strategies.

The first types of vehicles being developed are cars aimed at mass-market applications. These examples include the Nissan Leaf (Nissan, 2012), Peugeot iOn



(Autotrader, 2011), Mitsubishi i-MiEV (Mitsubishi, 2012), Renault Twizy and Zoe (Renault, 2012), Smart Electric Drive (Smart, 2012) and a few more examples. All of these vehicles are produced to a price as low as possible without compromising on quality or performance. These vehicles have been well received by much of the motoring press (Autocar, 2011; Autotrader, 2011; Car, 2011). The performance and quality is very much comparable to petrol and diesel cars and running costs are extremely low. Despite these positive attributes the mass market BEV is still struggling to achieve the high unit sales that these mainstream automotive OEMs expect. This is potentially because costs are too high in comparison with conventional ICEV and these BEVs have insufficient attributes improvements to justify this price premium.

The second type of BEV being marketed differs greatly to those being developed by some of the world's largest automotive OEMs. Tesla Motors is developing BEVs for niche markets. The company is one of the youngest car manufactures operating today and was founded in 2003 (Tesla Motors Inc, 2012). Many innovations such as the mass produced automobile and mobile phone have been the result of a visionary and innovative few. Almost every new technology is initially not recognised by the majority of industrial leaders and consumers. How does Tesla Motors differ from their mass-market rivals mentioned above? The standout reason is that Tesla Motors dismissed the route of cost minimisation in order to make their technologies cost competitive with ICE vehicles. They are seeking to take advantage of added value for BEVs and market their vehicles to niches.

Tesla first began selling their vehicles in 2008. They did not choose a hatchback, family car or saloon for their first vehicle; they chose a roadster. The Tesla roadster was expensive at US\$109,000; but had performance benefits with a 0-60mph acceleration time of 3.7 seconds. Tesla was aiming at the high-end performance market for its vehicles. By making an expensive, high performance car with distinguishable looks the technology can quickly gain added value from the consumer perspective. This has led to there being Tesla 'enthusiasts' who take their cars to automotive shows, racing events and take them touring, there is even a Tesla motors club. By creating revenue streams Tesla has been able to invest earnings into future products. The case of Tesla Motors is discussed in detail in chapter 6.

The introduction of the BEV is so far proving to be difficult. The reason for the introduction of BEVs being quite problematic is most likely due to the technological lock-in of petrol and diesel vehicles (Cowan and Hultén, 1996), the issues of any socio-technical change (Faber and Franken, 2009; Geels, 2004; Vasileiadou and Safarzyńska, 2010), and the issues of public perception and consumer preferences (Dattee and Weil, 2007). The story of the BEV demonstrates how technologies beneficial to society will not always achieve great success in the market. Indeed, BEVs still haven't been able to take the mass vehicle sector. But the adoption of BEVs into niches is a promising sign and the work of Tesla gives a positive outlook for the future of BEVs. Tesla's technologies are well aligned with the seven case studies of disruptive innovations. The observations made for historical disruptive innovations are true for Tesla. What is especially true is that their technologies are more expensive than incumbent vehicle technologies, the performance is worse in

some aspects (for example range and recharge time) and they are partially dependent upon the development of new infrastructure.

## **5.4 Identifying Disruptive Innovations**

After reviewing the historic successful disruptive innovations and the BEV it has been possible to develop an improved understanding of disruptive innovations. These lessons can be used to develop criteria that can then be used to identify whether technologies that have yet to enter the market will be disruptive. The criteria are based on three fundamental characteristics that are found to be present in disruptive innovations. However, there are exceptions to this, and for a technology to be a disruptive innovation it must meet at least two of these three criteria. This flexibility makes it easier to identify when a technology is a disruptive innovation, as in hindsight it was revealed that some technologies are still disruptive even when only fitting two of the criteria, such as quartz watches; quartz was disruptive to market leaders being made by different companies in different countries. They are also disruptive to end users changing the way in which watches could be used. The quartz watches required battery replacements rather than being power by mechanical movements and had increased accuracy. But quartz watches were not heavily reliant upon new infrastructure. The Nissan Leaf is disruptive to infrastructure and end users, but an existing market leader within the automotive sector produces the Leaf. If a technology is found to only meet one of the criteria then it is not a disruptive innovation; it is rather likely that it represents an incremental improvement in existing technology.

The criteria further developed below can be used to confirm that all of the historic case studies of disruptive innovations reviewed in this chapter were in fact disruptive innovations. Secondly the criteria can be used to assess whether a technology in the market penetration stage is a disruptive innovation to the current market. In this way it can be used to confirm that the BEV is a disruptive innovation. Finally, the criteria can be used to predict whether a new or innovative technology will be a disruptive innovation upon market entry. In this way the criteria would be used to state whether FCVs are a candidate disruptive innovation within the automotive sector and indeed many of the markets they could enter.

The predictive nature of the model is one of its most valuable assets. In this application the model is useful to both developers of disruptive innovations and to existing market leaders. Developers of disruptive innovations need to know whether a technology is a disruptive innovation so that they can develop a market entry strategy specific to its needs. The knowledge of the disruptive nature will also allow identification that the market entry of the new product will not be as simple as a process compared to the introduction of an incremental innovation.

In order to use the three criteria to assess whether an innovation, is disruptive or will be a candidate disruptive innovation some information is required regarding the incumbent and the potential disruptor. First for the incumbent the market leaders in the target market need to be identified, along with the users of the technology and what infrastructure the technology is reliant upon. For the potential disruptive innovation the producer of the new technology, who the target users are and how they will use the technology along with the infrastructure requirements need to be established. When this information is known the disruptor can be compared to the

incumbent. If the disruptor meets two or three of the criteria then it is a candidate disruptive innovation. Below the three point criteria are discussed and their usage is illustrated by making comparisons with BEVs.

1. Disruptive to Market Leaders: The manufacturers of the disruptive innovation are different companies to those producing the incumbent technologies.

The companies producing the disruptive innovations are not the same companies as the ones producing the incumbent technology. New market entrants disrupt existing companies producing the incumbent technologies leading to lost revenue and reduced market share. Non-market leading companies took many successful disruptive innovations to the market. However there are exceptions to this rule, and on occasions market leaders do develop disruptive innovations. For example mass-market BEVs are manufactured by mainstream original equipment manufacturers (OEMs), but they are still clearly a disruptive innovation, impacting infrastructure and end users. Furthermore the companies in the supply chain of these BEVs will differ greatly compared to an ICEV developed by any automotive OEM. Examples of this type of disruption include the Nissan Leaf and the Peugeot iOn. These BEVs produced by existing market leaders are less disruptive than a BEV being produced by a new market entrant. For example Tesla's BEVs (Tesla Motors Inc, 2012) are more disruptive to the existing automotive industry, as the OEM is a new company and the supply chain differs compared to the traditional automotive sector. Tesla is a new company with a disruptive innovation entering a market with established market leaders and technologies. Tesla Motors strategy is disruptive to market leaders, end users and infrastructure.

2. Disruptive to End Users: The different characteristics of disruptive innovations mean they are disruptive to end users, changing the way in which the technologies are used.

Disruptive innovations are disruptive to end users and consumers. The disruption arises because of a change in the way in which end users interact with the technology; historically successful disruptive innovations often required a behavioural change. The disruption to consumers can also be positive and is due to the benefits that the innovations provide giving adopters and improved user experience. One aspect of this could be the way in which users are required to interact with infrastructure. The BEV for example would be used differently to an ICEV, it would be plugged in at home over night to be refuelled rather than being driven to a refuelling station. Another aspect of disruption to end-users arises because BEVs have functional improvements compared to the incumbent technologies. The BEV is disruptive in this respect because it fulfils the same task as an ICEV, but has benefits over an ICEV. It is silent in operation, has zero tail pipe emissions and reduced running costs compared to an ICEV. The economic advantages that have been imposed by the government in the UK, for example, mean BEV's pay no road tax, no congestion charge and can be parked for free in some urban locations. The additional uses of an innovation often make it disruptive because it offers a compelling reason to buy as compared to incumbents.

3. Disruptive to Infrastructure: The disruptive innovation requires different infrastructure than the incumbent technology.

The introduction of BEVs would lead to disruption to the petroleum industry and its infrastructure. Existing infrastructure would be impacted negatively and new infrastructure would be needed. Currently charge points are sparsely distributed with most vehicles being usually recharged from home. Not all disruptive innovations do require new infrastructure, however. This is because not all technologies are heavily reliant upon infrastructure; additionally some disruptive innovations can utilise existing infrastructure. FCVs are heavily reliant upon new hydrogen refuelling infrastructure in order to ensure their success.

## **5.5 Conclusion**

The 7 examples of historic disruptive innovations and the example of the BEV have led to some useful insights into how innovations can achieve market entry. Disruptive innovations are often not recognised as a significant threat by established market leading companies. One reason for this is because the disruptive innovation will be expensive in comparison with the incumbents, and in order to it to achieve some market entry margins are likely to be lower, and hence profits smaller. Another reason for this is because the first market for disruptive innovations are niche markets which represent a small percentage of the entire market and are small, meaning low unit sales and low revenue generation. These innovations will also have some shortcomings, which often mean mass market appeal is low in the initial market entry stages. The new technology will crucially have some benefits for consumers. The mass market may often not desire these benefits, but some consumers in niches will value them. This combination between shortcomings and unique benefits again can lead to demand being low, further reiterating the importance of niche markets.

New technologies will require new infrastructure in many cases, this can mean initial market entry is difficult because of the need to establish an infrastructure at the same time as developing the innovation. Finally, because socio-technical systems are always evolving, the incumbent technology will one day resurge into niche markets, and the disruptor will reach the mass-market level and become the incumbent itself, until a new disruptor emerges. The most significant lesson for proponents of new technologies is the importance of niche markets and the presence of benefits that are demanded in these niches. Without the existence of these the success of the innovation will be unlikely. Further to this, once a product has entered a niche market it is critical to continually improve the technology such that it appeals to more early adopters and eventually later adopters.

Based on the three criteria suggested here FCVs are a disruptive innovation, requiring new infrastructure and allowing for additional uses over incumbent technologies. Whilst new market entrants do not produce FCVs, many components of FCVs such as the hydrogen tanks and FCs are. Proponents of FCVs hope that they will replace ICEVs and be the main source of motive power for vehicles (Dincer and Rosen, 2011; Martin et al., 2009; Neef, 2009; G. Offer et al., 2011). In order for FCVs to achieve this they will need to achieve market entry. They will ultimately need to be adopted by consumers, and this is dependent upon the vehicles having beneficial attributes that are desired by consumers in niche markets.



# CHAPTER 6

Fuel cell vehicles- Can lessons be learned from Tesla motors?

## Chapter 6 Can Lessons be learned from Tesla Motors?<sup>2</sup>

### 6.1 Introduction

Based on the insights gained in the previous chapter from the case studies of historical disruptive innovations it was decided that a more in-depth study of a particular innovation was needed. The innovation should share characteristics with FCVs in order to make it most relevant; therefore it should be an automotive innovation. In this case the innovation was chosen to be the BEV and specifically Tesla BEVs as the subject of this chapter. Tesla Motors was chosen, as it was the closest case to FCVs that the author was able to identify. The results of this historical case study are concerned with BEVs in the year 2014, therefore all the cost of ownership data is correct as of that year. This is the first year that the Model S and the Nissan Leaf were both on sale in the UK.

Both FCVs and Tesla BEVs are considered to be an innovation, both are ZEVs, both are fully or partly reliant upon the development of infrastructure and both exceed the cost of incumbent ICEVs. Table 4.1 shows a comparison between FCVs and Tesla along with other vehicles that were considered for this study. Unlike other BEV manufacturers who attempt to make their vehicles competitive with ICEVs, Tesla has been developing BEVs that are superior to ICEVs in some areas. To achieve this, the company has invested a lot in research and development and has secured 117

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<sup>2</sup> The results in this chapter are based on the publication Hardman, S., Shiu, E. & Steinberger-Wilckens, R., 2014. **Changing the fate of fuel cell vehicles: Can Lessons be Learned from Tesla Motors?** *International Journal of Hydrogen Energy*, 40(4)

patents with 258 patents pending. Its Model S BEV is a range leader at 265-314 miles, a pack cost leader by using already mass produced cells from Panasonic, and a charge rate leader achieving 50% charge in 30 minutes (Tesla Motors Inc, 2013a).

Table 6.1: Comparison between FCV, Tesla and other Electric Vehicles considered for this study.

Vehicle	Cost (USD)	New Infrastructure	Zero Emissions
Fuel Cell Vehicle	70,000	✓	✓
Tesla BEVs	75,000-95,000	✓	✓
Nissan Leaf	30,000	✓	✓
Toyota Plug-in Prius	30,000	×	×
Porsche Panamera Hybrid	96,000	×	×

Tesla's goal is to eventually release a mass market BEV, but they are rolling this out over a number of vehicle generations. According to CEO Elon Musk the company is pursuing a three-stage market entry strategy. Musk said in the 2013 shareholder meeting that it was always his intention to produce a mass market BEV (Tesla Motors Inc, 2013a); he reiterated this in the 2014 shareholder meeting (Tesla Motors Inc, 2014b). In order to reach mass-market entry the three-stage market entry process is:

1. Develop a high price low volume vehicle: The Tesla Roadster
2. Develop a mid price, mid volume vehicle: The Tesla Model S and Model X
3. Develop a low price, high volume vehicle: Due in 2017 (Called the Tesla Model 3 or III).

Tesla's CEO draws analogy against the mobile phone, which was able to achieve impressive technological development and cost reductions over successive generations (Hardman and Steinberger-Wilckens, 2014), but this occurred over a long time span. Tesla is trying to achieve this over a shorter period of time and with fewer generations. Tesla hope that the third generation model will be available from

around half the price of the Model S (Tesla Motors Inc, 2013a), which would mean it would be priced between US\$30,000-45,000 (£19,000-29,000).

## 6.2 Issues with Mass Market Entry

A key aspect in the market entry of BEVs is customer identification. When target customers are being discussed within the literature, key themes arise. It is commonly stated that early adopters of BEVs will potentially be highly educated, environmentally conscious and have oil supply concerns (Carley et al., 2013a; Garling and Thøgersen, 2001; Martin et al., 2009). Most studies overlook the need for BEV users to have higher incomes due to the high prices of BEVs. Table 6.2 shows prices of BEVs available in the UK in 2014. These high purchase prices are a major hurdle for mass market low-end encroachment market entry (Kley et al., 2011).

Table 6.2: On-the-road price of electric vehicles in the UK, excluding the £5000 BEV grant available off the purchase price (BMW, 2014; Citroen, 2013; Mitsubishi, 2012; Nissan, 2013a; Peugeot, 2012). \*Excludes battery rental at £70/month

	BMW i3	Citroen C-ZERO	Nissan Leaf	Peugeot iOn	Renault ZOE	Mitsubishi iMiEV
<b>Cost (£)</b>	£30,730	£26,216	£25,990	£26,216	£18,995*	£28,990
<b>Range (Miles)</b>	80-100	93	124	93	130	93

### 6.2.1 Price and Payback Times

Whilst BEV sales are increasing (Schneider, 2012), market uptake is still slow. A 2013 study found that intent to purchase a BEV is still very low (Carley et al., 2013a). Prospective customers see the main advantage of a BEV as potential fuel savings, however the initial purchase prices of BEVs compared to similar conventional

vehicles is too high to justify these fuel savings. Payback times are found to be unacceptably long (Carley et al., 2013a).

A comparison can be seen in Figure 6.1 showing the running costs of a Nissan Leaf with 4 similar rival vehicles. These calculations are based on the information in Table 6.3. Figure 6.1 shows that the Nissan Leaf does not become the cheapest vehicle type almost 4 years of ownership. However, when the battery is leased (£70 per month) the Leaf is the lowest cost option from year 0, due to the reduced purchase price, but becomes more expensive than a non-leased Nissan Leaf after 5, a Hybrid after 8 years and a Diesel ICE after 10 years due high battery lease costs. It is important to consider that these findings are based on the £5000 UK government grant that was available for plug-in vehicles. A cost comparison in the absence of these grants can be seen Figure 6.2. This shows how important the grants are at present. The information in Figure 6.2 suggests that the Leaf does not become the cheapest vehicle type until more than 10 years when compared to a hybrid vehicle or an efficient diesel vehicle. Even when grants are taken into account it is not cheaper until 3 to 4 years into ownership. BEV grants are not available in all nations meaning ICEVs are still often cost effective due to unacceptably long payback periods of the BEV. Suggesting to consumers that mass market BEVs can save you money, on the basis of lower fuel costs alone, would be misleading according to these findings.

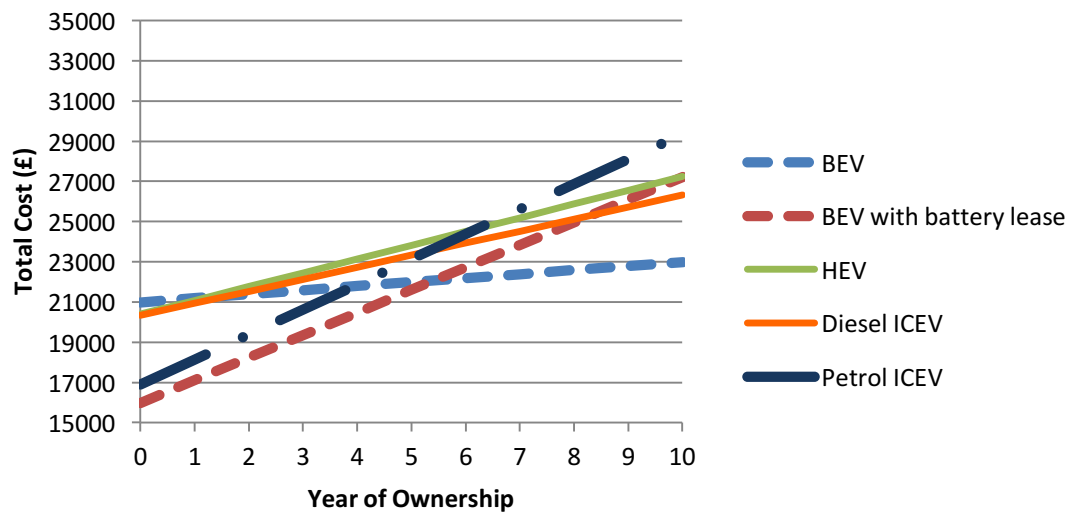


Figure 6.1: Running costs per year of the Nissan Leaf Compared to its rival hybrid, ICE and diesel cars. Based on purchase price, fuel costs and road tax, this is including the government £5000 plug in vehicle grant (Nissan, 2013a, 2013b; Toyota, 2013; Volkswagen, 2013).

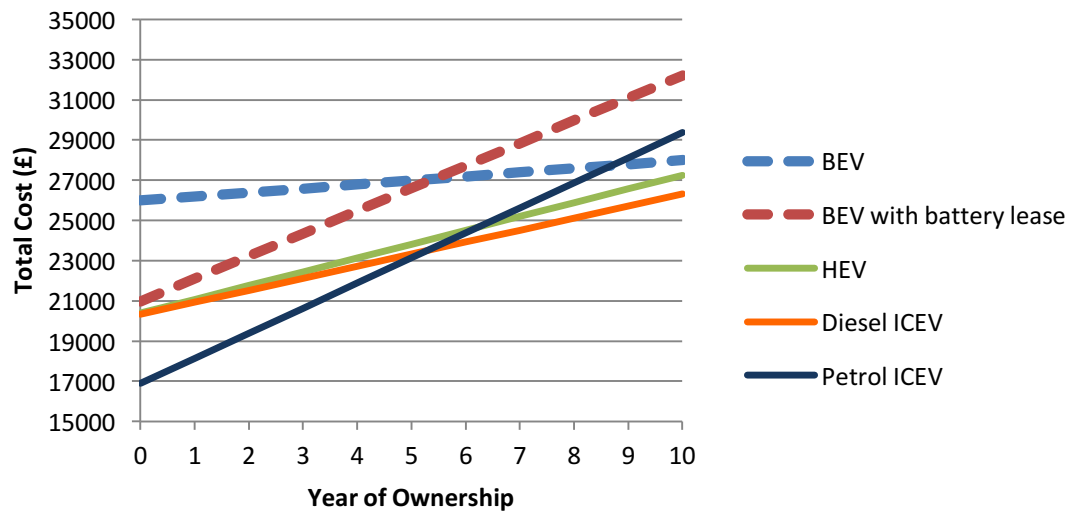


Figure 6.2: Running costs per year of the Nissan Leaf Compared to its rival hybrid, ICE and diesel cars. Based on purchase price, fuel costs and road tax, this is excluding the government £5000 plug in vehicle grant (Nissan, 2013a, 2013b; Toyota, 2013; Volkswagen, 2013).

Table 6.3: Running costs per year the Nissan Leaf and its rival vehicles (British Gas, 2014; National Statistics, 2011; Nissan, 2013a, 2013b; Toyota, 2013; Volkswagen, 2013).

	Nissan Leaf	Nissan Leaf (Battery Lease)	Toyota Auris Hybrid (HEV)	VW Golf Bluemotion (Diesel ICEV)	Nissan Qashqai (Petrol ICEV)
<b>Purchase Price (£)</b>	25,990	20,990	20,395	20,335	16,895
<b>Electric Vehicle Grant (£)</b>	5,000	5,000	na	na	na
<b>Battery Lease (£ year<sup>-1</sup>)</b>	na	922	na	na	na
<b>Tax (£ year<sup>-1</sup>)</b>	0	0	0	0	130
<b>Combined Cycle (MPG)</b>	na	na	74.3	88.3	45.6
<b>Consumption (kWh mile<sup>-1</sup>)</b>	0.34	0.34	na	na	na
<b>Electricity Cost (£ kWh<sup>-1</sup>)</b>	0.07	0.07	na	na	na
<b>Fuel usage (L year<sup>-1</sup>)</b>	na	na	515.79	434.02	840.43
<b>Fuel Cost (£ L<sup>-1</sup>)</b>	na	na	1.329	1.379	1.33
<b>Fuel Cost (£ year<sup>-1</sup>)</b>	200.6	200.6	685.49	598.51	1,116.93
<b>Running Costs (£ year<sup>-1</sup>)</b>	200.63	1,122.63	685.49	598.51	1,246.93

## 6.2.2 Range

For consumers limited range is an issue, and a barrier to purchasing a BEV. Ranges of mass market BEVs are around 87 (Smart, 2012) to 124 miles (Nissan, 2012), according to NEDC (New European Drive Cycle) estimations. For many customers this limited range wouldn't be an issue; Pearre et al (Pearre et al., 2011) suggested that 75% of the US population could substitute an ICE for a BEV with limited disruption due to range. However, drivers still perceive the range as an issue. Daily, many people don't drive further than the range of a BEV (87-124 miles), but on a

monthly or annual basis journeys exceeding these ranges are more common. Therefore a second vehicle would be required on these occasions. BEVs would form part of a multi-vehicle fleet, with a second ICEV being available for journeys exceeding the BEVs range (Franke et al., 2012).

### **6.2.3 Core & Ancillary Attributes**

In addition to mass market BEVs having lower ranges compared to ICEV there are other core attributes with lower performance values. Mass market BEVs have similar 0-60mph acceleration times, but lower top speeds. This means that vehicles have core attributes that are worse than the incumbents, and many other core attributes, such as the visual appearance of the vehicle and the level of equipment (sat nav, radio, air conditioning etc.) remain unchanged. These performance shortcomings would lead to an assumption that these types of BEVs should be entering markets via low-end encroachment, but their high prices prevent this from being a possibility. As a result they are marketed at higher prices than ICEVs despite their shortcomings.

### **6.2.4 Consumer Perceptions**

Often consumers develop an image of a technology or product over a long period of time and their perception is based on previous experience and exposure. This is problematic for BEVs since current BEVs are much more advanced than previous ones. However, people may base their perceptions of BEVs based on previous prevailing opinions. In the UK it is suggested that buyers' perceptions of BEVs are negative because of previous experiences & observations of Milk Floats, Electric Golf carts and Quadricycle BEVs such as the G-wiz (Burgess et al., 2013). As a result of this, consumer's opinion of the core attributes of a BEV are even lower than the



actual core values. There is a need to change these views in order to increase market uptake.

Garling & Thøgersen stated in 2001 that “*Higher prices, limited ranges, less loading capacities and lower top speeds are not a desirable package*” Whilst this statement was made in 2001 it still remains partly true today. Compared to their most direct rivals electric vehicles do fall short in these areas. Because of these inadequacies, it was suggested that BEVs should enter markets with low introductory prices and that drivers of high-end cars are unlikely to purchase a BEV over an ICEV (Garling and Thøgersen, 2001). As a result of statements such as these many automotive manufactures have gone down the route of cost minimisation for mass market BEVs, but this leads to the core values of the technology being inferior to incumbent vehicles, and this causes the negative views of BEVs to continue. And indeed costs have not been able to be reduced to a level that makes them cost competitive compared to ICEVs.

The poor core attributes of BEVs discussed here are only present in BEVs for mass markets, such as the Nissan Leaf, Peugeot iOn, Mitsubishi i-MiEV, and Smart electric. As will be shown, one automotive company has produced BEVs with none of the disadvantages of these BEVs and superior core and ancillary attributes compared to ICEVs. This company has developed a high value BEV without shortcomings of mass market BEVs. This high-end encroachment market entry approach has long been used within the automotive sector and indeed many other market sectors. However with BEVs & FCVs it has been neglected by many automotive organisations, with most companies seeking a route of mass-market entry through a cost reduction strategy. Some of these companies have seen success,

especially Nissan with the Leaf; however this case study is less relevant for FCVs due to the lower purchase price of the Leaf. The price point of the Leaf is currently unattainable for FCVs and so this low cost market entry route is not appropriate for FCVs. This is the reason for the Leaf or any other BEV not being the subject of this study.

## **6.3 The Market Entry of Tesla Motors**

### **6.3.1 Tesla Roadster**

In the 2013 shareholder meeting, Tesla CEO Elon Musk remarked that Tesla could have launched their first BEV for around US\$70,000 (£45,000) (Tesla Motors Inc, 2013a). At this price the vehicle would be a mid size family car with poor range and performance. By increasing the purchase price by US\$30,000 (£19,000) Tesla were able to make a sports car that was much more appealing for buyers. In this market the vehicle is competitive on price, performance, looks and range. The key to Tesla's market entry was the correct market positioning of their first vehicle.

When the Roadster was launched in 2008 it was the first federally compliant BEV in the US. It was the first highway capable BEV and had market leading range on each charge (245 miles). Tesla aimed this vehicle at owners of sports cars such as the Porsche 911. In this market Tesla was able to compete on price and performance in addition to having 70% lower running costs, according to Tesla. This means that the Tesla Roadster compared to a Porsche 911 will payback in less than 3 years (Figure 6.3). This is achieved without any purchase incentives. In the UK the running costs of the Tesla could be as low as £220 per year if charged on a low cost electricity tariff (£0.07/kW economy 7 rate) (British Gas, 2014), this is compared to over £2000 in

petrol and road tax for the Porsche. The high running costs for the Porsche are due to low fuel efficiency (29.4mpg), high UK fuel cost and high UK road tax.

Table 6.4: Running costs per year the Tesla Roadster and a rival ICEV the Porsche 911 (British Gas, 2014; Porsche, 2013a; Tesla Motors Inc, 2013b).

	<b>Tesla Roadster</b>	<b>Porsche 911</b>
<b>Purchase Price (£)</b>	88795	83448
<b>Electric Vehicle Grant (£)</b>	0	0
<b>Battery Lease (£ year<sup>-1</sup>)</b>	0	0
<b>Tax (£ year<sup>-1</sup>)</b>	0	460
<b>Combined Cycle (MPG)</b>	0	29.7
<b>Consumption (kWh/mile)</b>	0.37	0
<b>Electricity Cost (£/kW)</b>	0.07	0
<b>Fuel usage (L year<sup>-1</sup>)</b>	0	1,290.35
<b>Fuel Cost (£ L<sup>-1</sup>)</b>	0	1.329
<b>Fuel Cost (£ year<sup>-1</sup>)</b>	218.3	1,714.88
<b>Running Costs (£ year<sup>-1</sup>)</b>	218.34	2,174.88

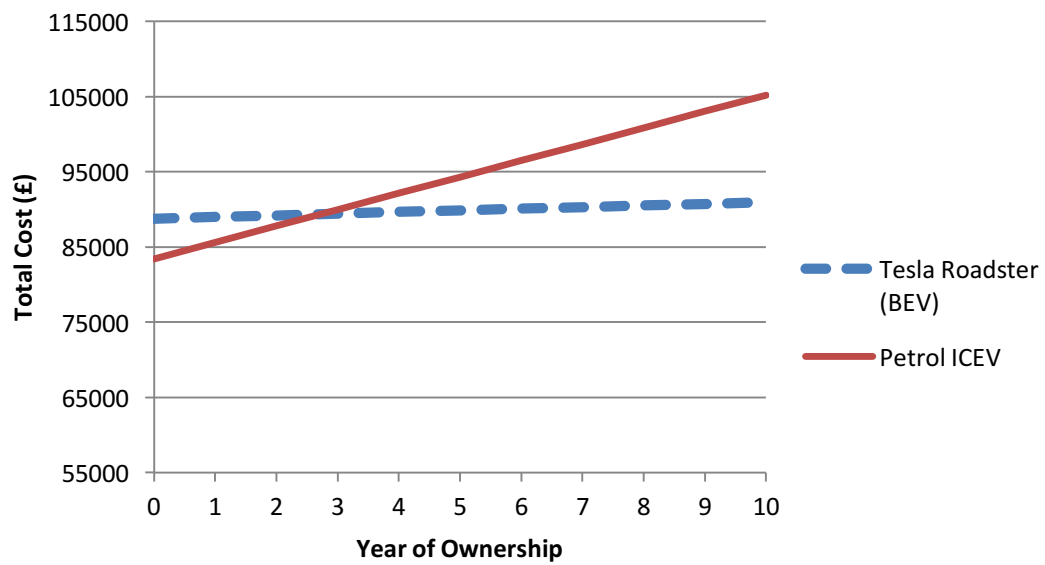


Figure 6.3: Running costs per year of the Tesla Roadster Compared to a rival ICEV the Porsche 911 (Porsche, 2013a; Tesla Motors Inc, 2013c).

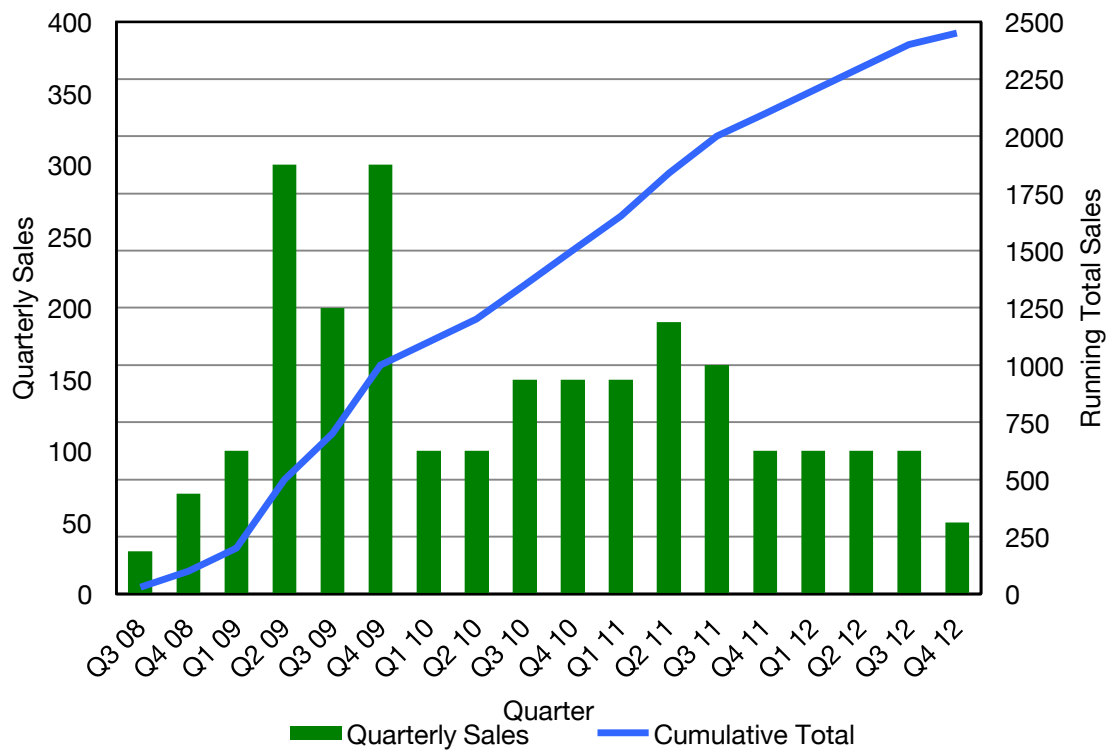


Figure 6.4: Tesla Roadster sales from Q3 2008 to Q2 2012.

### 6.3.2 Model S

The technology in the Roadster was designed so that it could serve as a foundation for future models. The Model S is Tesla second vehicle, and is designed for a wider market than the Roadster. The vehicle is more practical, having 5 seats with the option of 7 and is available for a lower price of US\$70,000 (£48,000) in the US after the US\$7,500 (£5200) federal tax credit. This makes the car price-competitive with similar cars in the luxury sedan class; Tesla lists Audi, BMW, Lexus and Mercedes as competition for the Model S. In this market the Model S is price competitive and has strong core and ancillary attributes compared with these vehicles. Due to vehicles in this class being inefficient due to their large engines and weights the Model S can provide significant savings in running costs.

Figure 6.5 shows that even without any subsidies the Model S will payback within 4 years of ownership, compared to its most efficient and lowest cost rival. This is 6 years faster than the payback time of the Nissan Leaf. With the UK's £5000 grant, which it is eligible for, the Model S is immediately cheaper. The running costs of the Model S would be £220 per year based on £0 road tax, 8,430 miles of driving, £0.07/kWh electricity cost (British Gas, 2014) and 0.37 kWh consumption per mile (Tesla Motors Inc, 2013d).

Table 6.5: Running costs per year the Tesla Model S and its rival vehicles (BMW, 2013; British Gas, 2014; Porsche, 2013b, 2013c; Tesla Motors Inc, 2013d).

	Tesla Model S	BMW M5	Porsche Panamera Diesel	Porsche Panamera Hybrid
Purchase Price (£)	73700	73505	69222	88967
Electric Vehicle Grant (£)	0	0	0	0
Battery Lease (£ year <sup>-1</sup> )	0	0	0	0
Tax (£ year <sup>-1</sup> )	0	475	200	0
Combined Cycle (MPG)	0	28.5	45.6	91.1
Consumption (kWh mile <sup>-1</sup> )	0.37	0	0	0
Electricity Cost (£ kWh <sup>-1</sup> )	0.07	0	0	0
Fuel usage (L year <sup>-1</sup> )	0	1,344.69	840.43	420.68
Fuel Cost (£ L <sup>-1</sup> )	0	1.329	1.383	1.329
Fuel Cost (£ year <sup>-1</sup> )	218.3	1,787.09	1,162.31	559.08
Running Costs (£ year <sup>-1</sup> )	218.34	2,262.09	1,362.31	559.08

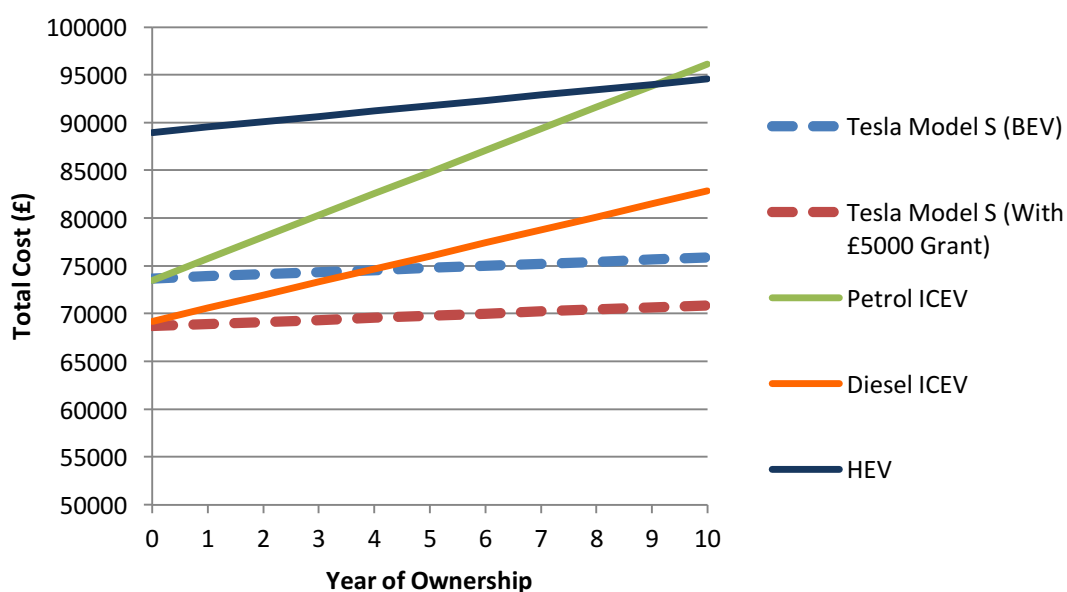


Figure 6.5: Running costs per year of the Tesla Model Compared to incumbent ICE, diesel and hybrids vehicles (BMW, 2013; Porsche, 2013b, 2013c; Tesla Motors Inc, 2013d).

Deliveries of the Model S began in June 2012, and by December 2012 3,100 had been delivered with over 15,000 reserved. By Q4 of 2014 46,000 Model S's were delivered to customers, these were mainly in North America and the Model S was the top selling BEV in the US throughout 2013 beating the Mercedes S Class, Porsche Panamera, Audi A8 and BMW 7 Series (Tesla Motors Inc, 2014c). Sales figures, which is measured by the number of vehicles delivered, of the Model S can be seen in Figure 6.6. In late 2013 sales of the Model S began in Europe and Asia. Orders for the Model S continue to come in at a rate of 20,000 per annum. By the end of 2015 delivered of the Model S were 109,000 units.

The Model S represents the first part of the second stage of Tesla's three-stage market entry. The Model S is a mid to high price medium volume production car. The S is cost competitive to other luxury sedans in the market (Figure 6.5). The Model S has received numerous awards including car of the year (Motor Trend, 2013) and was Consumer Reports highest scoring car ever tested (Consumer Reports, 2013).

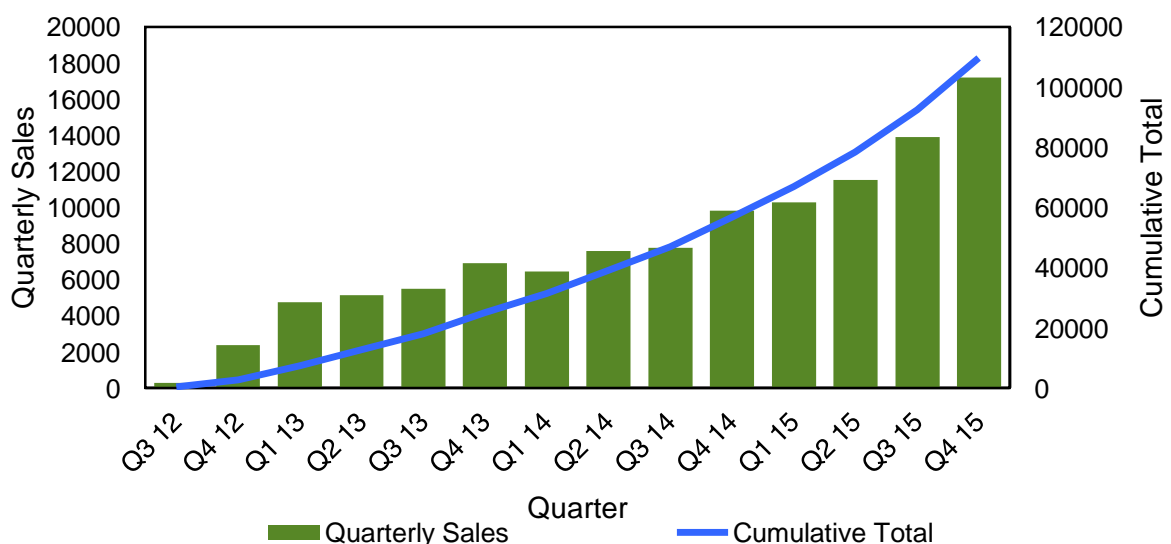


Figure 6.6: Tesla Model S Sales measured by number of deliverers from Q3 2012 to Q3 2014.

### **6.3.3 Model X**

The Model X shares the same basic architecture as the Model S, but with a larger body and 4-wheel drive. The Model X is the first BEV with dual motor 4-wheel drive. It also has innovative doors allowing easy access to the back two rows of seats. The Model X sits in the second stage of Tesla's market entry strategy. The Model X is being sold at a similar price and volume as the Model S. By having a larger interior capacity and 4x4 drive it is hoped that the X will open up additional markets for Tesla. Model X deliveries began in Q4 2015, with initial delivering being low due to difficulties in ramping up production numbers. In total 208 were delivered in Q4 2015, with the expectation that deliveries will increase in 2016.

### **6.3.4 Supercharger Network**

Many innovative and disruptive technologies require new infrastructure; BEVs specifically required electric recharging infrastructure. BEVs can be charged with standard mains supply electricity but this results in slow charge rates, and can be restrictive giving few opportunities for charging when away from home. Tesla is developing a network of supercharging stations. These stations can charge the Model S's batteries by 50% in 30mins. This high speed charging is achieved using 120kW max charge rates and with batteries that have a lower taper point than other batteries (Tesla Motors Inc, 2013a). The supercharger network is free to use forever, when the option is purchased with the vehicle or comes as standard with the vehicle. In 2015 the Supercharger network will cover 98% of the population in the US. At the time of this investigation there were 129 superchargers in the US, 89 in Europe and 34 in Asia. Tesla planed on this doubling before the end of 2014 (Tesla Motors Inc,



2014c), and at the end of 2015 there were 560 operational supercharger stations globally. The purpose of this network is so that Tesla can show that it is possible to drive long distances in BEVs. A team from Tesla completed a coast-to-coast road trip in the Model S to prove this. The network does not support the Tesla Roadster due to technological incompatibility (Tesla Motors Inc, 2013a). Tesla has also began development of the Supercharger network in Europe, beginning in Norway, which already has one of the highest concentrations of BEVs in Europe (CleanTechnica, 2013) and the first Model S to be sold in Europe were sold in Norway (Tesla Motors Inc, 2013e), with 500 being delivered to customers between August and September 2013 (International Business Times, 2013). In addition to Norway, Supercharger stations are now in Germany, The Netherlands, Austria, Switzerland and the UK (Tesla Motors Inc, 2014d).

### **6.3.5 Sales Channels**

Many innovative and disruptive technologies do not enter markets via traditional sales channels. Tesla did not follow the traditional model of franchises that mainstream automotive companies follow. Tesla sell all vehicles through their own sales channels. Disruptive technologies can be complex; keeping the sales in-house prevents misinformation developing around a product. Poor sales and marketing advice in the early days of a market entry can potentially be damaging. By owning their own sales channels Tesla is able to offer customers compelling customer service. Tesla's sales channels achieve higher efficiencies and higher sales capture over traditional franchise models (Tesla Motors Inc, 2013f). Currently this model is being battled by US OEMs who have been successful banning Tesla from selling

vehicles directly to the public in the state of Texas (Tesla Motors Inc, 2013g). Tesla takes advantage of increased revenue share from vehicles sold; by selling the products directly, margins can be made smaller, this can lead to the purchase price of the technology being marginally lowered making the product more competitive in the market.

## **6.4 Conclusion**

It is clear that Tesla is not an example of immediate high-end encroachment where a product is introduced at the top of an existing market. Prior to the introduction of the Tesla Roadster there was no market for BEV sport cars. Tesla's market entry method is one of new market high-end encroachment. New market high-end encroachment is where a product is sold only to new customers in new markets, products are improved along core attributes and add new ancillary dimensions targeted to consumers at the very high-end of the market. It is important to understand what type of encroachment pattern a product is taking, as this will have implications on future product development and marketing activities (Van Orden et al., 2011). Often it is hard to identify which category a new technology fits into, and often experts will put a technology in two different categories (Van Orden et al., 2011). With Tesla it could be debated whether the product is new market or new attribute high-end encroachment. It is the opinion of the author that Tesla is an example of new market encroachment rather than new attribute encroachment. Compared to existing ICE automobiles Tesla has improved core attributes, but also adds ancillary attributes. Core attribute improvements are high acceleration, high speed, bold looks and low running costs of Tesla vehicles, this combined with ancillary attributes of silent drive train, zero tailpipe

emissions, convenience of never needing to visit a refuelling station and cost savings means that it is different to any ICEV on offer. The vehicles also brand equity due to them being viewed as 'cool'.

The study of Tesla Motors clearly shows how it is possible for a high-end technology to enter markets via the route of high-end encroachment. This gives hope to developers of FCVs, which are significantly more expensive than comparable ICEVs. These price premiums will not be an issue if core and ancillary attributes are improved allowing FCVs to enter market via high-end encroachment. But if FCVs do not have added value features over ICEVs their price premiums may be unacceptable to consumers. Whether or not FCVs have sufficient beneficial attributes compared to ICEVs is somewhat unclear at this stage, and this is investigated later in this thesis.

# CHAPTER 7

Mobile phone infrastructure development-  
lessons for the development of a  
hydrogen infrastructure

## Chapter 7    Mobile phone infrastructure development- Lessons for the development of a hydrogen infrastructure<sup>3</sup>

### 7.1    Introduction

The development of new infrastructure is often a requirement in the introduction of innovations. This is true for FCVs, which are reliant upon a hydrogen-refuelling infrastructure. This chapter looks at the development an entirely new infrastructure in detail in order to understand firstly how infrastructure can be developed to support the market entry of an innovation. The case study in the example presented here has key similarities to hydrogen infrastructure. Meaning there are some insights that FCVs and hydrogen infrastructure can learn from this example.

#### 7.1.1 Introduction to mobile phones

The development of infrastructure to support new technologies and products is an integral aspect in the introduction of innovations. Many innovations would be useless without their associated infrastructure. There is great interest in the development of hydrogen infrastructure to support FCV market entry (Eberle et al., 2012; Melaina, 2003; Melaina et al., 2012; Michalski et al., 2011; Park et al., 2011; Yang and Ogden, 2007). Many case studies aim at solving some of the current issues of infrastructural development by investigating historical cases. Previous studies use the example of how ICEV infrastructure was developed in the late 1800s and early 1900s (Geels,

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<sup>3</sup> The results in this chapter are based on the publication Hardman, S. & Steinberger-Wilckens, R., 2014. **Mobile phone infrastructure development: Lessons for the development of a hydrogen infrastructure.** *International Journal of Hydrogen Energy*, 39(16)

2005; Melaina, 2007). This example is less helpful to the current situation. This is because for ICEVs there was an existing petroleum supply network that supplied petroleum for lighting, stationary petrol generators, and the farming industry (Geels, 2005). The availability of infrastructure was a compelling reason to purchase an ICEV over competitive vehicles. FCVs require a totally new refuelling infrastructure; hydrogen is a commodity that is not supplied by the current transport fuel industry but by specialised companies, which are not accessible to consumers. Therefore the example of petroleum infrastructure development is not relevant for FCVs. What is needed is an example of a new infrastructure being developed to support an innovation that had no prior infrastructure available. Fortunately, a very instructive example exists, this being the mobile phone and its network infrastructure. The mobile phone was a disruptive innovation heavily reliant upon infrastructure for it to gain success. FCVs share this characteristic as they are a potentially disruptive innovation (Hardman et al., 2013) and are heavily reliant upon infrastructure.

Understanding how mobile communication networks were developed will allow an understanding of how new infrastructure is implemented. This chapter will show that pre-development of infrastructure is vital to the successful introduction of any innovation requiring totally new infrastructure. This is highlighted by the fact that network development began around 5 years before the first commercial mobile phone was sold to the public.

The mobile phone was a disruptive innovation; this can be confirmed using the 3-point disruptive technology criteria and the founder of disruptive innovation theory, also states that mobile phones are a disruptive innovation to land line telephones (Christensen, 2013a). Mobile phones had clear added functionality over landline

phones; this functionality did however come at a cost, and this was an exceptionally high purchase price. With economies of scale and technological improvements handset unit costs were continually reduced and in around 30 years the mobile phone went from high cost low volume series in niche markets to occupying the mass market. At the same time it has been continually developed from a simple device capable of telephone calls to the smart phones of today.

When the team at Motorola headed by Martin Cooper invented the mobile phone in 1973 (Goggin, 2009), it created a new market sector. The mobile phone had clear benefits. The mobile phone met an existing need; it became possible to instantly communicate regardless of location, and be able to contact people in the event of an emergency situation. The mobile phone provided convenience greater than any other communication technology did before. Land lines, phone booths and pagers could not meet these needs. The cost of using a mobile phone far exceeded the costs of communication via existing means, but people were willing to pay due to the added convenience. One further reason for the rapid adoption of the mobile was thanks to it becoming a status symbol (Steinberger-Wilckens, 2002), which meant social prestige was associated with the phone.

By 2015 the global mobile phone handset market reached US\$340 billion (Markets and Markets, 2013). The extent of market penetration of mobile phones is vast. Globally there are 85 phone subscriptions per 100 people. In developed countries like the UK 39% of people own a smart phone, there are more phone subscriptions than people and 52% of voice communications are made via a mobile phone (Ofcom, 2012). Figure 7.1 and Figure 7.2 show the global and UK increases in mobile phone subscriptions. In the UK it can be seen that growth has begun to slow and the market

may have almost reached saturation. The recent global growth trend in mobile phone subscriptions is being maintained by emerging economies.

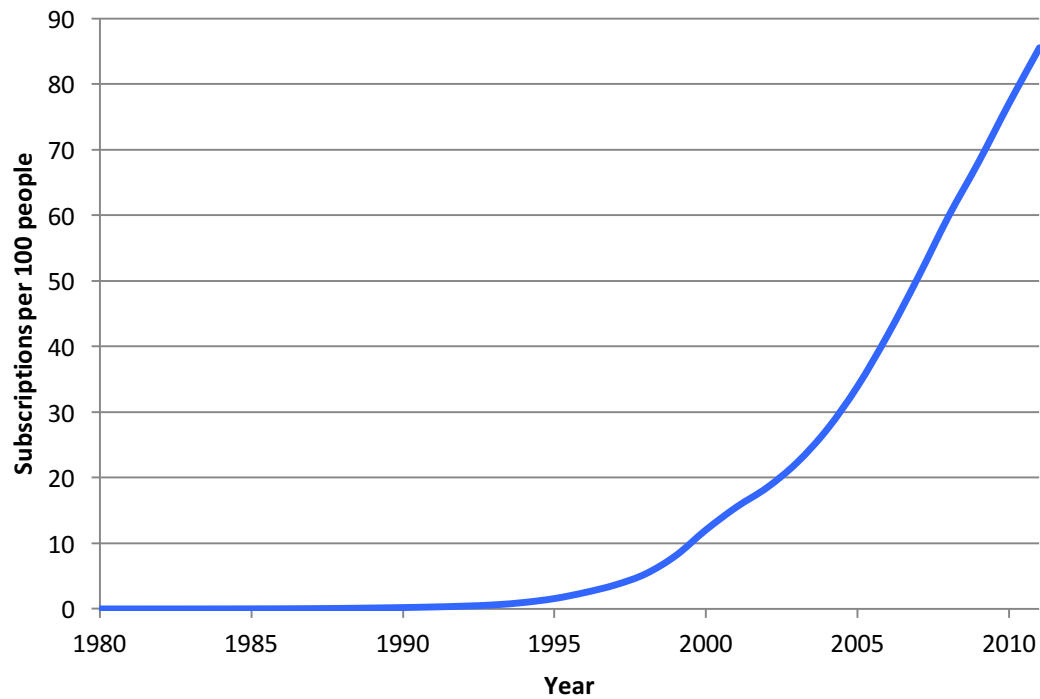


Figure 7.1: Global Mobile Phone Subscriptions per 100 people (The World Bank, 2013).



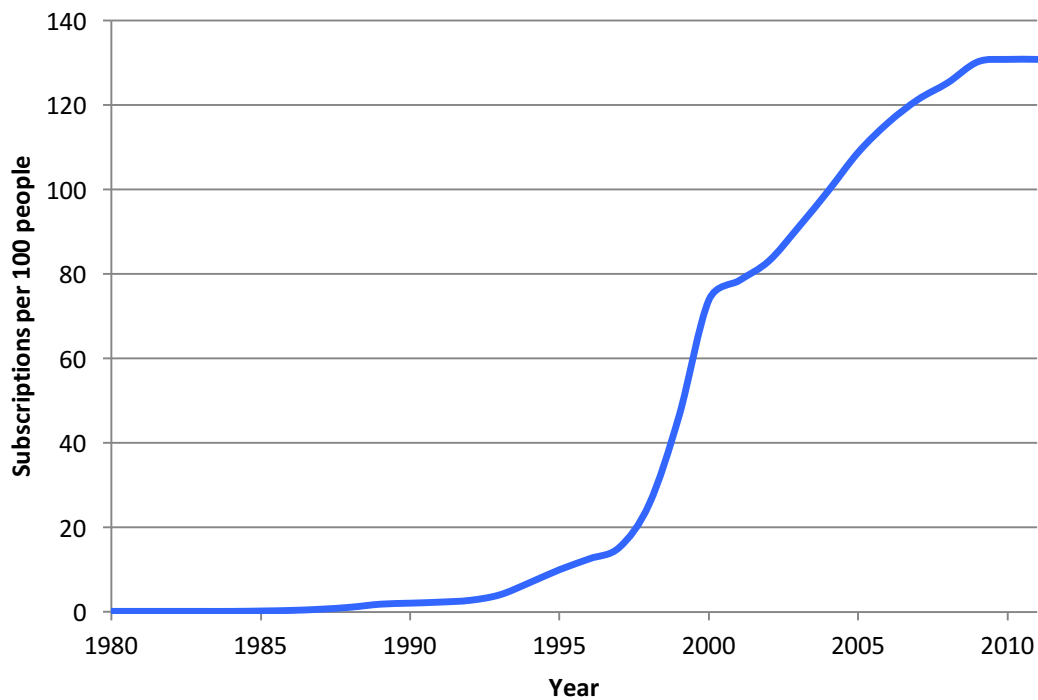


Figure 7.2: UK Mobile Phone Subscriptions per 100 people; note that there are more subscriptions than inhabitants in the UK. This is because many people have more than one phone, or SIM card (The World Bank, 2013).

### 7.1.2 Mobile Phone Development

The first mobile phone calls were typically made from cars or mobile radiotelephones. In the 1940s, these calls were made from devices weighing around 35kgs. The first truly mobile phone call was made in 1973, it was done using a hand held device invented by Motorola. In 1983 Motorola launched its DynaTac mobile phone to the market. This was the first commercial mobile phone. The device cost around US\$4000 (Pocovnicu, 2009). These phones worked off the first-generation (1G) networks. It was not until the arrival of second-generation GSM technology and thanks to lower priced handsets that mobile phones began seeing faster rates of adoption. The development of the mobile phone occurred at a rapid pace; mobile

handset weight was continually reduced from close to 800g to less than 160g in only 20 years (Figure 7.3). At the same time the price of handsets fell from over £2,500 (US\$4,000) to less than £250 (Figure 7.4). Costs have in recent years begun to rise due to increasing functionality through added capabilities. It is remarkable that handsets were continually improved and at the same time cost and weight reductions were achieved.

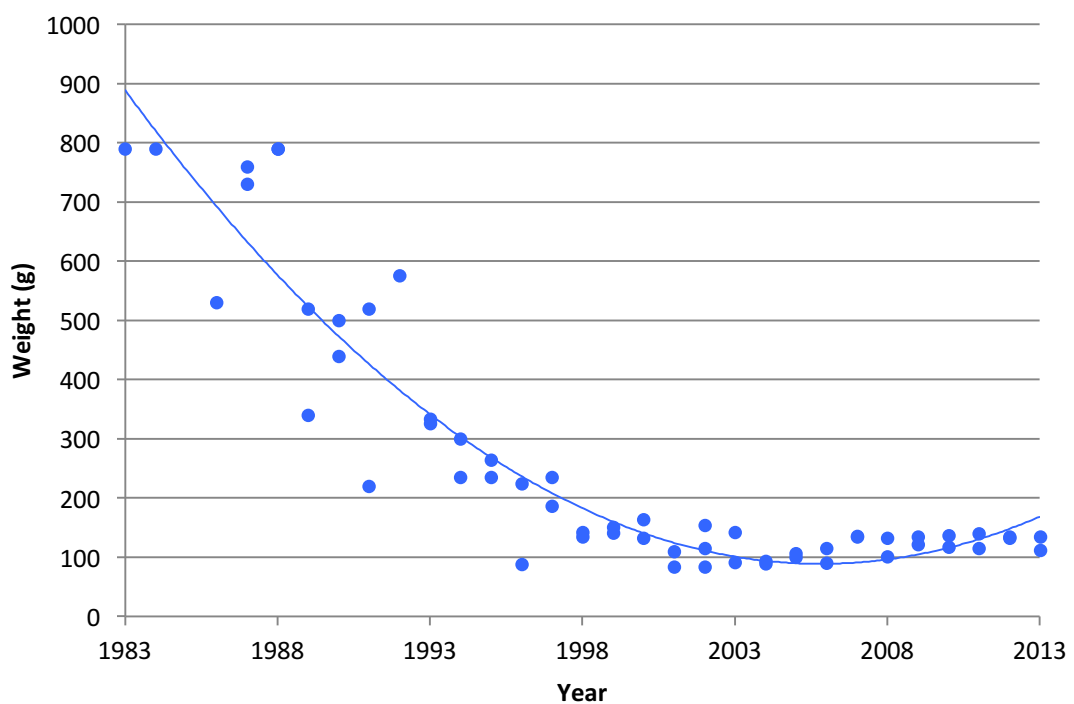


Figure 7.3: Phone handset weight from 1983-Present (Adam Nielson, 2005; Apple, 2013; Carita Koskinen, 2011; CNET, 2005, 2003; David Bowman, n.d.; iDSA, 2010; Mobile Burn, 2006; Mobile Gazette, 2012a, 2012b; Mobile Phone History, 2007, n.d., n.d.; Mobile Phone History, 2012; Nokia Museum, 2013, 2012, n.d.; Phone Arena, 2010; Tech Radar, 2012; The Telegraph, 2009; University of Salford, 2012; Vogel, 2005; Web Designer Depot, 2013)

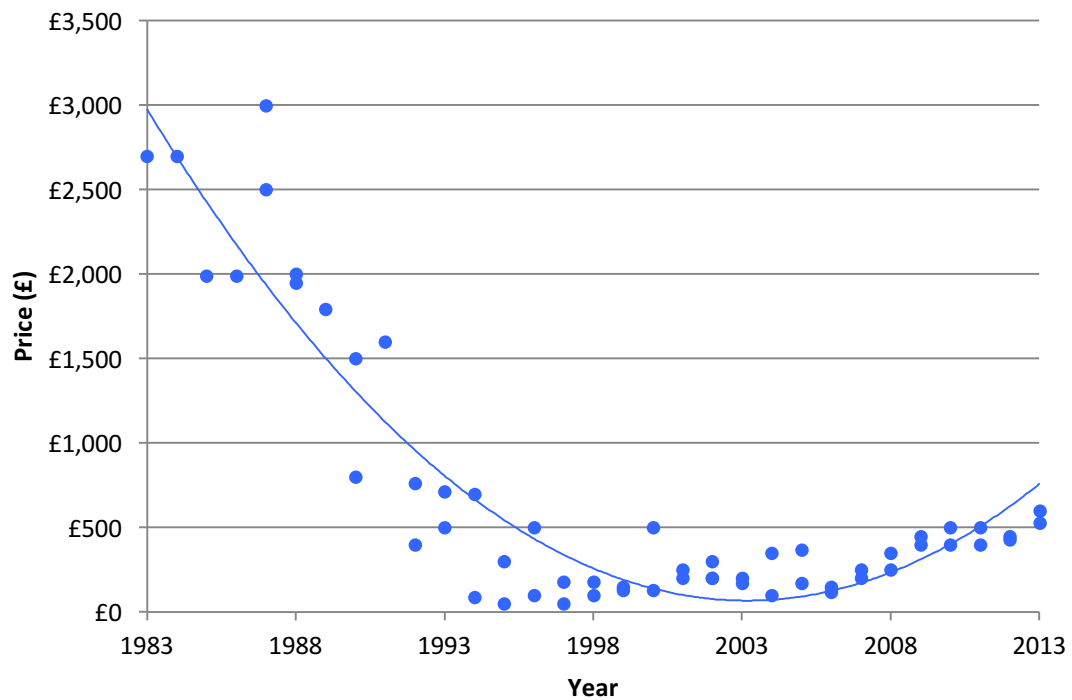


Figure 7.4: Phone handset price from 1983-Present (Adam Nielson, 2005; Apple, 2013; Carita Koskinen, 2011; CNET, 2005, 2003; David Bowman, n.d.; iDSA, 2010; Mobile Burn, 2006; Mobile Gazette, 2012a, 2012b; Mobile Phone History, 2007, n.d., n.d.; Mobile Phone History, 2012; Nokia Museum, 2013, 2012, n.d.; Phone Arena, 2010; Tech Radar, 2012; The Telegraph, 2009; University of Salford, 2012; Vogel, 2005; Web Designer Depot, 2013)

## 7.2 Results and Discussion

The first part of this study presents an overview of each generation of mobile networks, from 0G to 4G networks of today. This section does not provide quantitative evidence about infrastructure development, rather it is descriptive and is intended to build context. The most important results in this study are presented in section 7.2.5. This section presents quantitative data that shows how mobile phone infrastructure was developed prior to market entry occurring. This data is partly taken from (GSMA, 2012) and (Nokia Siemens Networks, 2011). The data only accounts

for GSM networks and not more advanced 3G or 4G networks. GSM networks the most wide spread globally accounting for 90% population coverage. The coverage of advanced 3G and 4G networks are not measured here, these networks did not help with the initial market entry of mobiles phones, rather they are improving the functionality of the mobile phone as it goes through incremental product development.

Mobile phone use would not be possible without the development of infrastructure. Consumers would not purchase a device that could not be used. As with FCVs there was a need to make a decision to invest in infrastructure before the market entry of the product could begin. The decision to invest is not an easy one, as the economic incentives to develop an infrastructure that currently has no customers are hard to identify. Nevertheless, without the development of infrastructure any technology reliant upon it will not be successful. An overview of the increase in network capabilities can be seen in Figure 7.5 as measured by download rates, also know as band rates.

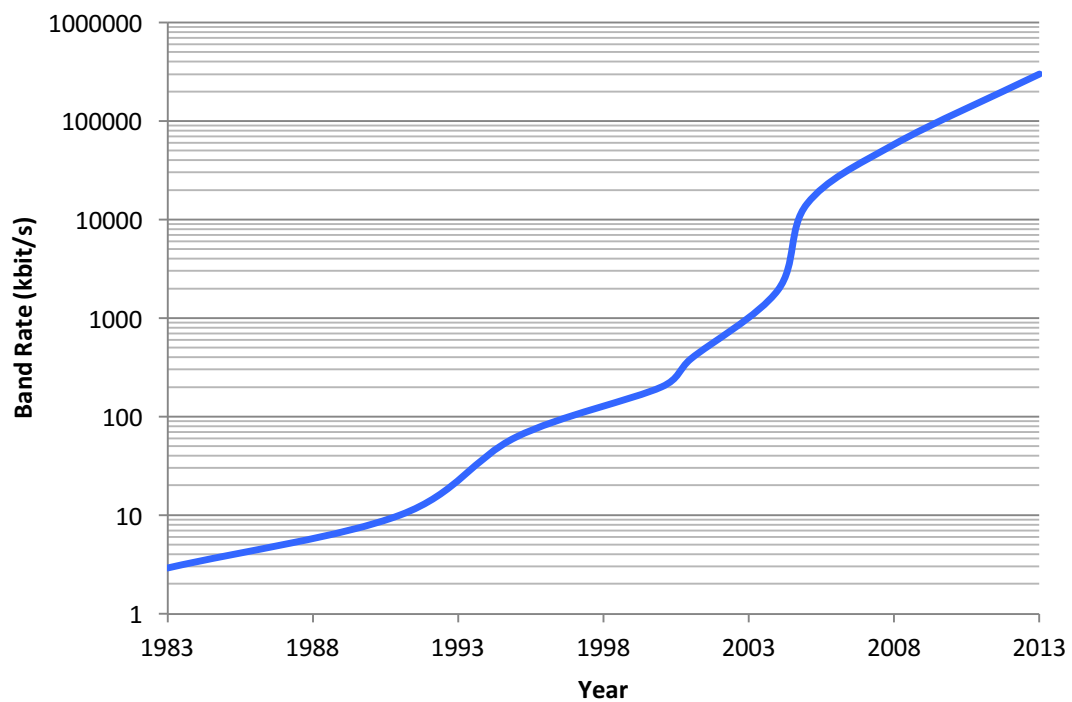


Figure 7.5: Mobile phone download band rates in Kbit/s from 1983-2012 (Parkvall and Astely, 2009; Patil et al., 2012; Scharnhorst et al., 2006).

### 7.2.1 Early Infrastructure (0G)

0G networks predated mobile phone networks and were designed to support car/truck phones and mobile radiotelephones. The most successful 0G network, by population coverage, was ARP which operated in Finland between 1971-2000. ARP achieved 100% coverage by 1978 with only 140 base stations. The network quickly became congested with high demand and so Nordic Mobile Telephone (NMT) was introduced in 1981, this was a 1G network. Congestion of 0G networks was an issue in many areas including North American and most of Europe. Eventually the networks could no longer supply the high call volumes. Nevertheless these networks

highlighted the potential success that a truly mobile phone and appropriate infrastructure could achieve.

### **7.2.2 First Generation (1G)**

Prior to the introduction of the mobile phone no infrastructure existed that could support mobile communications and without this infrastructure the mobile phone would have been useless. The only comparable system was the 0G network mentioned above, but mobile phones did not use these networks. For the mobile phone a pre-development phase was needed in order to develop the necessary infrastructure to support their use. The first network was the first generation (1G) network; this was an analogue system and wide scale introductions began in the 1980s. 1G networks allowed for widespread voice communication within country borders. The first networks became operational in 1979 in Tokyo, Japan; European networks became operational in 1980 and USA in Chicago, in 1977 (Kumar et al., 2010). This was 4-7 years after Motorola demonstrated the first mobile phone in 1973; this first phone call was made using just one phone mast and a short call was made locally. In 1984, 11 years after the first mobile phone call and 7 years after investments into infrastructure first began, the first commercially available mobile phone was released into the market. This meant that infrastructure developers had to wait up to 7 years before they would see a return on the substantial investments that went into establishing the infrastructure. Even after the launch of the DynaTac, mobile phone market penetration was still low until the 1990s, when prices fell below US\$1000 per unit and subscriptions began to increase. Many of the original 1G networks were located in urban areas. Urban areas are centres of population, trade

and economy, so they are suitable areas for the implementation of new infrastructure. By initially concentrating investments in high population density areas, a relatively large proportion of the population could be covered with a limited amount of investment. Examples of this were the US mobile networks. In the US, Advanced Mobile Phone Systems (AMPS) was first launched in Chicago. This first network covered an area of 2100 square miles and comprised of only 10 base stations. Networks were then continually expanded from high population density areas to less population dense areas as consumer uptake began to increase.

These original networks were developed within individual nations, thereby limiting usage to within the country's boundaries. Although small in comparison with today's networks, these original networks were still expensive due to not benefiting from economies of scale with large numbers of users (Vriendt et al., 2002). Early networks included Advanced Mobile Phone System (AMPS), Nordic Mobile Telephone (NMT) and Total Access Communication System (TACS). AMPS became operational across most of the US in 1982.

In the US and Canada, 1G networks were launched by a system of companies headed by Bell Telephone Company (AT & T, 2013). This was an advantage as it lowered the amount of investment risk each firm was exposed to. Many of the companies investing in these networks were providers of landline telephones and radio communication companies. Crucially, mobile phone companies, such as Motorola, were involved due to their vested interest in increasing mobile phone uptake. Motorola invested both time and money into network development, inventing some of the technologies that networks used and investing in network expansions.

The original network technologies were invented and patented by Motorola (Cooper et al., 1975).

### **7.2.3 Second Generation (2G)**

The second generation (2G) network was digital rather than analogue; development began towards the end of the 1980s. 2G networks are known as GSM (Groupe Speciale Mobile), this is the most widespread network in the world in terms of area coverage. GSM was established to allow for pan European communication on a single digital cellular network. GSM became operational in 1991, but compatible handsets did not become available until 1992 (Vriendt et al., 2002). Worldwide, in 2007, 90% of mobile phone users use GSM in their voice communications (GSMA, 2007). The development of these networks supported data services for the first time. It was hoped that by the end of the 20th century 20 million users would use GSM, the actual number exceeded 250 million. GSM allowed for international roaming and cross border communications via mobile phones (Kumar et al., 2010). The standard was originally developed for European use, but is now used worldwide.

2G networks have been continually upgraded to cope with increased demand. The first upgrade was to 2.5G also known as GPRS and then to 2.75G also known as EDGE (Enhanced Data rate for Global Evolution). The upgrade to EDGE began in USA first in 2002 (Vriendt et al., 2002). These evolutions took the mobile phone network closer to the 3G networks. GSM was originally only designed for voice communication, GPRS and EDGE allowed for faster data communication and enhanced internet access.



### **7.2.4 Third Generation (3G)**

In 2002 demand began to shift from mainly voice and SMS communication to data communication. Network operators responded to the demand and began looking into increasing network capabilities; GPRS and EDGE being interim solutions until this development could be completed. The 3rd generation network became to be known as only 3G. The first commercial network became available in Japan in 2001, closely followed by South Korea in 2002 (Kumar et al., 2010). 3G allowed for a substantial increase in data and voice communication capacities over previous networks (Tan et al., 2007). 3G is far more limited in its coverage, compared to GSM networks, only covering around 11% (Vriendt et al., 2002) of global distribution compared to 90% for GSM (GSMA, 2007). The majority of 3G network users are in developed countries. In the UK, 99.1% of mobile phone users have access to 3G from at least one network provider (Ofcom, 2012). The next generation of mobile networks is 4G, 4G is also known as IMT-Advanced (Parkvall and Astely, 2009). The 4G networks are all being launched in urban and high population areas. The roll out of 4G is not reviewed here as it is not important for this study, 4G is part of the continual evolution of phone networks by increasing band rates compared to 3G.

### **7.2.5 Predevelopment of Infrastructure**

As was previously mentioned the first commercial mobile phone was released for sale 7 years after the first network was developed. Clearly work into network development began prior to mobile phones being released for sale. Consumers would not have been willing to adopt a phone without being able to make phone calls. This pre-development needs to be quantified. Therefore Figure 7.6 shows the

percentage population coverage of GSM mobile networks and mobile phone subscriptions per 100 people. The figure clearly shows that networks were expanded significantly before consumers adopted mobile phones. By the year 2000 40% of the global population had access to GSM networks, it was not until 2006 that there were 40 mobile subscriptions per 100 people, a 6-year gap. A similar trend can be seen prior to 2000. After 2000 the gap between population coverage and subscriptions began to narrow to around 5 years, with 85% of the population having access to GSM in 2007, and in 2011 there being 85 subscriptions per 100 people.

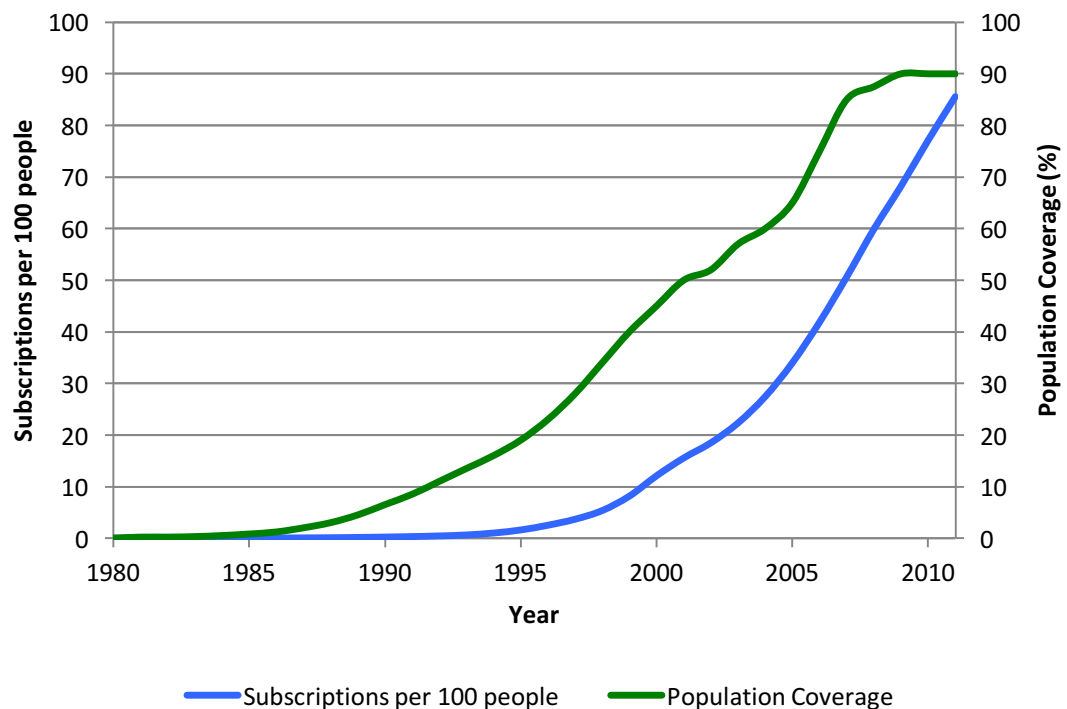


Figure 7.6: Worldwide Mobile phone market penetration and the development of mobile phone infrastructure for GSM (GSMA, 2012; Nokia Siemens Networks, 2011; The World Bank, 2013).

## **7.3 Lessons for Hydrogen Infrastructure**

### **7.3.1 Infrastructure Requirement**

Based on the findings presented above and data shown in Figure 7.6 implications can be drawn for the development of a hydrogen infrastructure. The above data have been applied to existing projections of FCV market share up until 2050. Two projections have been used. The first (Figure 7.7) is based on California's Advanced Clean Car Program (CACCP) predictions (California Air Resources Board, 2012). The second scenario (Figure 7.8) is based on the UK's Department of Energy and Climate Change's (DECC) 2050 Pathways Report (Department of Energy and Climate Change, 2013). The DECC data represents more conservative predictions for FCV market share in comparison to the CACCP predictions.

The secondary y-axes on Figure 7.7 and Figure 7.8 represent the percentage of vehicle users who would need to have access to hydrogen refuelling infrastructure so that the market predictions from DECC and CACCP can be met. It is important that percentage of vehicle users is used rather than percentage of the total population. This is done so that the infrastructure numbers relate properly to the FCV market share data, which also does not measure FCVs in the entire population; the data measures the percentage of FCVs specifically within the automotive sector. Access to refuelling infrastructure is defined as a maximum travelling distance of 5 miles to a filling station, a figure taken from (Melaina, 2003).

The most outstanding message of the infrastructural development scenarios is that hydrogen infrastructure development must occur approximately 5 years before market penetration of FCVs can be expected to occur. This 5 year lead-time is

instrumental in creating a market that is ready for FCVs. Both scenarios indicate FCV market entry occurring in 2020 and reaching high market shares by 2025, this would mean that investments into a hydrogen infrastructure would need to begin by 2015 with larger investments needed by 2020. Without these investments the market uptake of FCVs could be lower than is the UK DECC and CACCP predictions.

If by 2050, according to California's Advanced Clean Car program predictions (Figure 7.7), FCVs will make up 59% of light duty vehicles on Californian roads 59% of the vehicle users would need to have access to hydrogen infrastructure by 2045. Based on the DECC predictions of 20% FCV market share by 2050, 20% of the vehicle users would need access to hydrogen infrastructure by the year 2045. In the first 5 years it is probable that FCV market penetration would be very low with the only vehicles being in demonstration projects or a small number of early adopters, as is the current situation in California with 179 FCVs being deployed (California Air Resources Board, 2015). The lack of existing markets for FCVs is unavoidable and a market will not be able to grow until some baseline hydrogen infrastructure has been constructed. The recommendation made here is that a 5-year lead-time is the best strategy for hydrogen infrastructure since this will lead to smoother market entry for FCVs. If this 5 year lead time is not in place the level of market penetration of FCVs will lag behind the predictions from the DECC and CACCP.

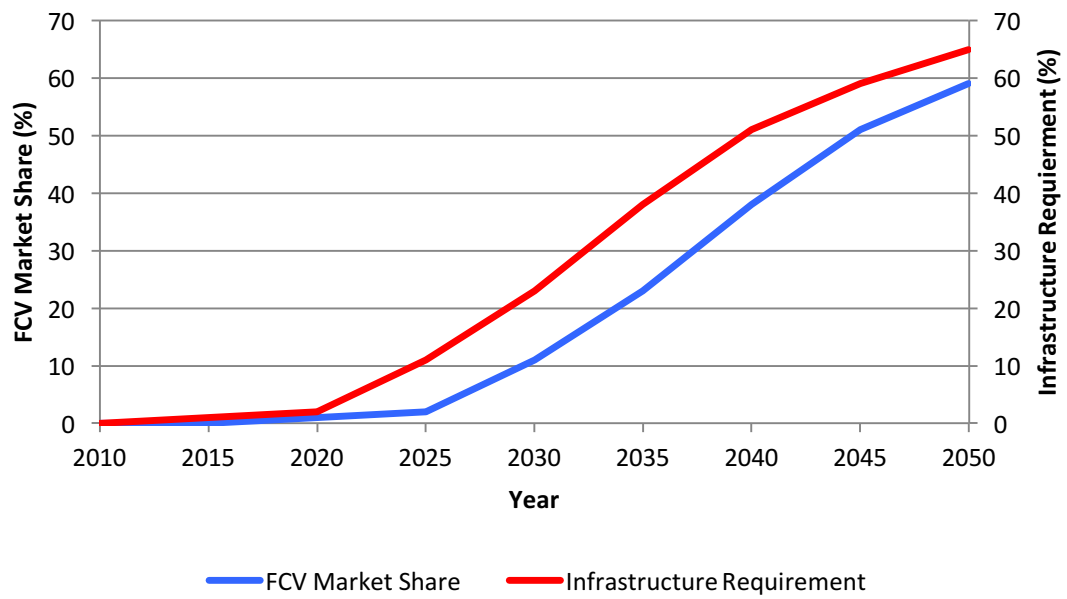


Figure 7.7: FCV Market share based on California's Advanced Clean Car program predictions of on-road light duty vehicle fleet (California Air Resources Board, 2012) and the infrastructure that will be required in order to support this market entry.

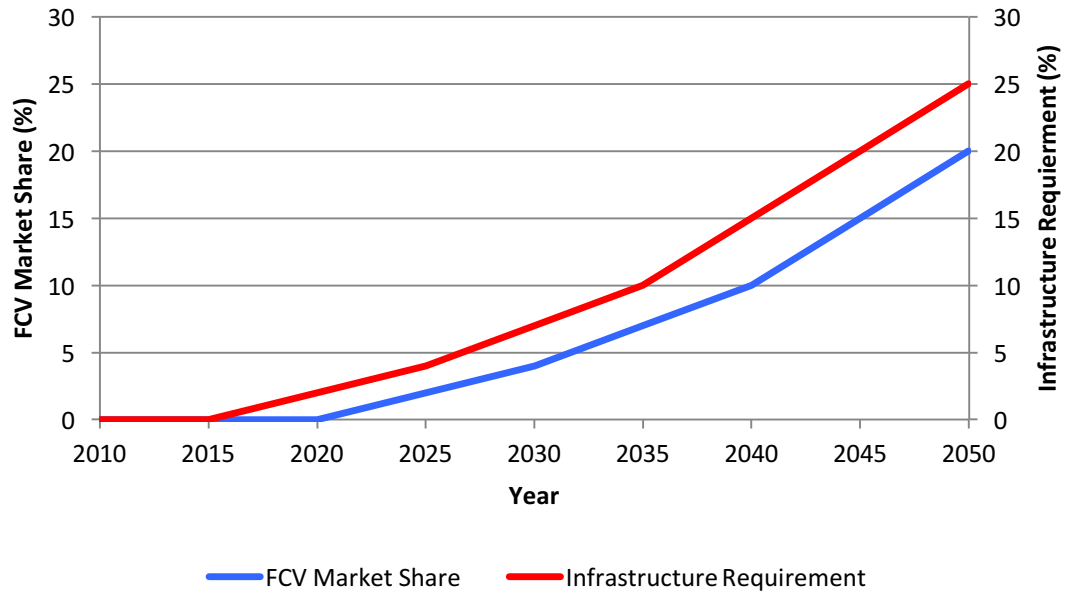


Figure 7.8: FCV Market share based on UK DECC 2050 Pathways Report miles travelled by vehicle type (Department of Energy and Climate Change, 2013) and the infrastructure that will be required in order to support this market entry.

### **7.3.2 Number of Refuelling Stations**

It is important to consider what is meant by access to infrastructure. FCV owners cannot be expected to travel significant distances in order to reach a filling station. It is assumed that the maximum theoretical distance travelled to reach a hydrogen filling station would be 5 miles. This distance is based on a study by Melaina and would mean that in the US it would take a maximum of 17 minutes to reach a station (travelling at an average of 25mph) (Melaina, 2003; Melaina et al., 2012). Based on these figures to cover 100% of the UK 1,198 hydrogen filling stations would be needed as an absolute minimum. This is a similar figure to the 1,150 stations suggested by UK H2 Mobility (UK H2 Mobility, 2013).

For California 100% coverage could be reached with 2085 filling stations as an absolute minimum. Figure 7.9 & Figure 7.10 show the number of filling stations that would be required in California and the UK, respectively, to meet the CACCP and DECC FCV predictions. 21 filling stations were needed, by the end 2015, in California. The actual figure was 9 that were accessible to the public. For the UK, where the market introduction is expected to happen later, 24 filling stations are needed by 2020. These figures represent the absolute minimum number of filling stations required to allow the vehicle users access to a hydrogen filling station within 5 miles. It would be more beneficial to have a greater number of filling stations to prevent congestion and to give FCV users more filling options.

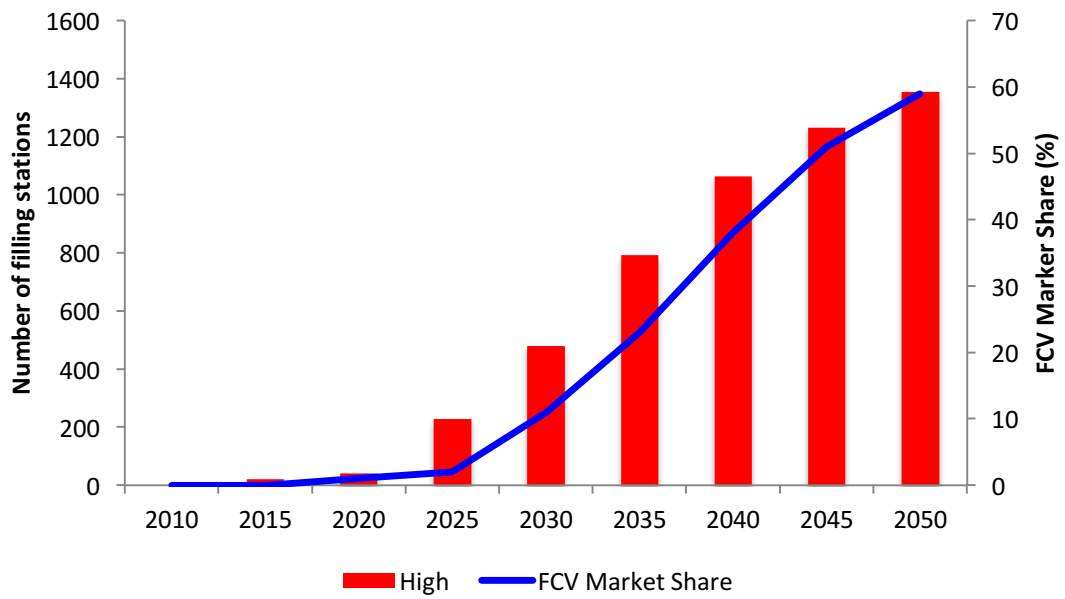


Figure 7.9: FCV Market share based on California's Advanced Clean Car program predictions of on road light duty vehicle fleet (California Air Resources Board, 2012) and the number of hydrogen filling stations that will be required in order to support this market entry.

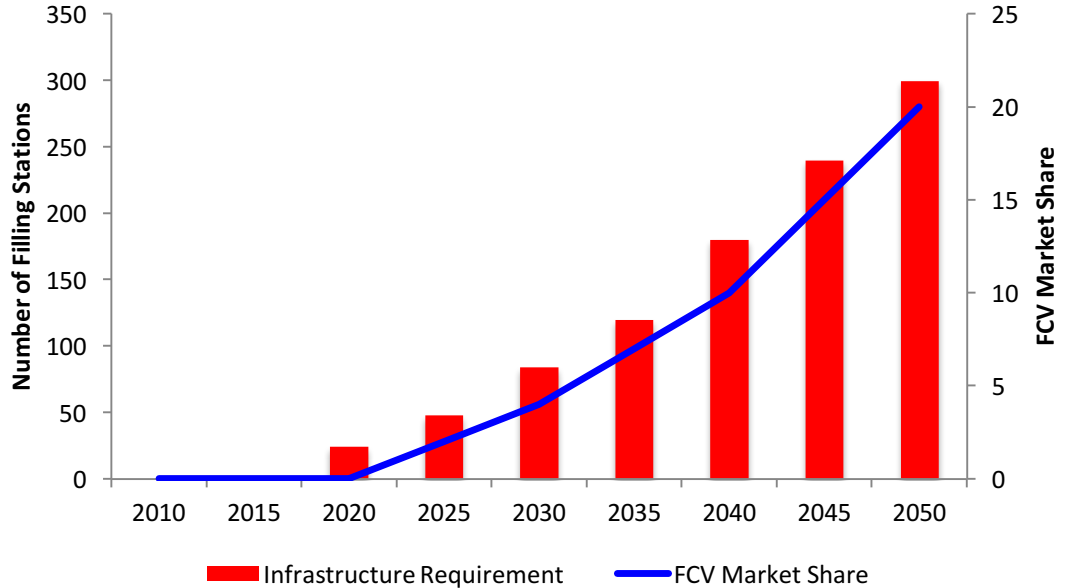


Figure 7.10: FCV Market share based on UK DECC 2050 Pathways Report miles travelled by vehicle type (Department of Energy and Climate Change, 2013) and the number of hydrogen filling stations that will be required in order to support this market entry.

These absolute minimum hydrogen filling station numbers mean that for the UK there would be 14,000 FCVs per filling station. The current ratio for ICEV to petrol stations is 4,011 vehicles per 1 station based on 34.5 million vehicles on the roads (RAC Foundation, 2013) and 8,600 filling stations in the UK (UK PIA, 2013). In California there is a ratio of 3,831 vehicles per filling station, based on 31.8 million vehicles (Department of Motor Vehicles, 2011) and 8,300 filling stations (The California Energy Commission, 2012). Therefore it would be sensible to increase the number of hydrogen filling stations by a 2 or 3 times so that each filling station serves a similar number of vehicles as petrol stations serve currently. This will ensure demand for hydrogen can be met at any time. More appropriate numbers of filling stations can be seen in Figure 7.11 & Figure 7.12. Figure 7.11 shows low, medium and high scenarios for the number of hydrogen filling stations required to meet the FCV market entry predictions based on California's Advanced Clean Car programme predictions of on-road light duty vehicle fleet (California Air Resources Board, 2012). Figure 7.12 shows low, medium and high scenarios for the number of hydrogen filling stations in the UK in order to support the UK DECC 2050 Pathways Report (Department of Energy and Climate Change, 2013) predictions for FCV market entry. Careful selection of the locations of these stations would obviously be crucial. Areas with a large number of potential early adopters of FCVs would need to be targeted first as well as areas with high proportion of vehicle users. This thesis does not look at specific locations of hydrogen filling stations.

What these scenarios clearly illustrate is that there is an existing need to invest in hydrogen infrastructure in California and a need to do the same in the UK by 2020. Without these infrastructural investments uptake of FCVs will be lower than what the



current scenarios are predicting. This would clearly be detrimental to the market uptake of FCVs. The 5 year lead-time of infrastructural development resulted in the successful introduction of the mobile phone. A 5 year lead-time could also be crucial to a successful market uptake FCVs.

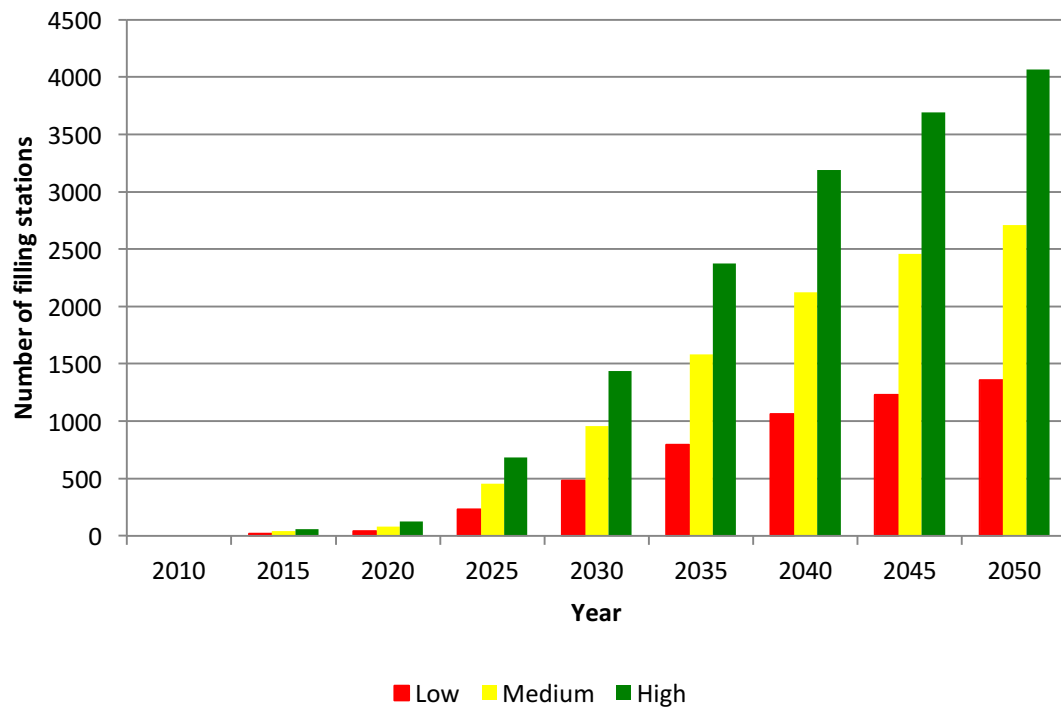


Figure 7.11: Low, Medium and High scenarios for the number of filling stations required in California to support FCV market entry based on California's Advanced Clean Car program predictions of on road light duty vehicle fleet (California Air Resources Board, 2012).

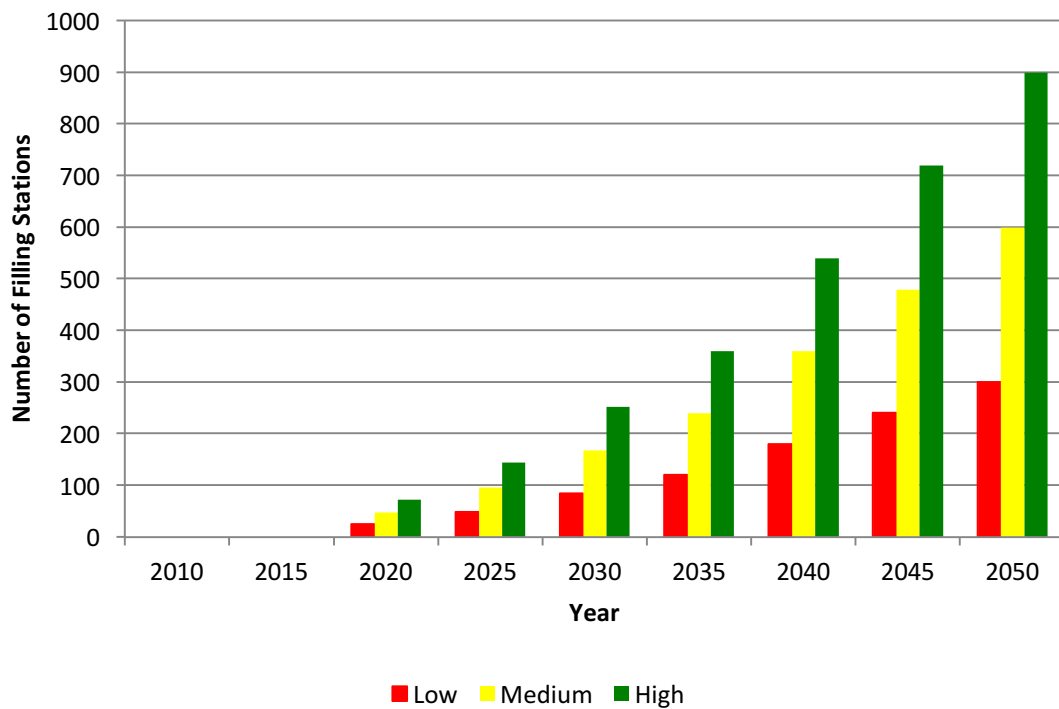


Figure 7.12: Low, Medium and High scenarios for the number of filling stations required in the UK to support FCV market entry based on the UK DECC 2050 Pathways Report (Department of Energy and Climate Change, 2013).

## 7.4 Conclusion & Discussion

Proponents of FCVs and hydrogen infrastructure are experiencing a predicament. There is currently no significant market for FCVs partly because there is no hydrogen infrastructure. Further to this, infrastructure providers may not invest into a hydrogen infrastructure because there is no demand for FCVs. The only solution to this is to pre-develop a hydrogen infrastructure in order to create a basis on which consumers can use FCVs. The situation that exists today for FCVs existed 30 years ago for the mobile phone. But mobile phone developers, telecom infrastructure providers and telecom network developers eventually came together and jointly invested in the pre-development of infrastructure. The mobile phone would not have been as successful

as it is today without these early investments. The organisations making the initial investments into mobile networks were both communication providers and handset OEMs. In this way investment into FCV infrastructure should be done in part by incumbent oil companies and existing hydrogen producers. Further to this it is important that automotive OEMs and FCV developers invest into the infrastructure that will support their products. With a larger number of investors involved in the introduction of a hydrogen infrastructure, costs will be lowered and risks shared. Governments are keen to see hydrogen infrastructure developed for energy security, environmental and societal reasons and they should also invest in this. Some projects involving a large number of stakeholders are underway. The UK H2 Mobility project brings in some of the stakeholders mentioned above but does not include oil companies. The recommendations made in this chapter align with those made by the UK H2 mobility project. The project outlines a roadmap to 1,150 hydrogen filling stations covering the entire UK by 2030 (UK H2 Mobility, 2013). These figures may be sufficient to support the market entry figures suggested by the UK DECC. If the H2 mobility project is a success it could result in the smooth market uptake of FCVs in the UK. The California Energy Commission in the USA awarded funds for the construction of filling stations (Fuel Cell Today, 2013a; The California Energy Commission, 2015), with recent funding meaning there should be 54 stations under development with the goal of 100 by 2020, which also aligns with the suggested numbers in this chapter.

The suggestion of having automotive OEMs invest into infrastructure is a divergence from their current business models. As was mentioned previously Tesla Motors are investing in BEV recharging infrastructure to support the market introduction of its

own vehicles (Tesla Motors Inc, 2013c). Supercharger stations cost between US\$150,000 and US\$300,000 and as of the end of 2015 there were 560 in North America, Europe and Asia (Tesla Motors Inc, 2013c). This means that the networks have cost between US\$84 and US\$168 million to date. FCV developers should learn from this and not be coy when considering investments into a hydrogen infrastructure if the vehicles are to be at all successful.

An alternative method, although not the recommendation being made here, is infrastructure development alongside centralised FCV fleet introductions. FCs are now seeing widespread applications in a number of niche markets; in both stationary and mobile power. One such mobile power niche is material handling equipment. Large fleets of forklift trucks are now in use (Fuel Cell Today, 2013b; Hardman et al., 2014a; Plug Power, 2013). These fleets are used alongside an onsite filling station that provides hydrogen. FC road vehicle fleets could operate centrally by utilising this existing infrastructure. This type of operation would be most useful to transport authorities and delivery companies, but could also be used to support the introduction of FCVs to the general public. This method would be less risky in terms of economic investment as there would be a guaranteed customer base; however, it is unlikely to facilitate a rapid increase in the consumer uptake of FCVs. What could be more useful is if these types of schemes were used as pilot and demonstration projects that can be used to prove the market for FCVs before the wide scale development of infrastructure. The results of these can inform the wider scale development of hydrogen infrastructure.

# CHAPTER 8

Comparing high-end and low-end  
adopters of battery electric vehicles

## Chapter 8 Comparing high-end and low-end adopters of battery electric vehicles<sup>4</sup>

### 8.1 Introduction to Battery Electric Vehicles

This chapter, and the following 2 chapters (Chapter 9 and Chapter 10) explore consumer adoption of BEVs. The aim of these chapters is to build an understanding of who adopts BEVs, why they adopt them, the benefits of owning them, and the importance of financial incentives toward the adoption decision. The results in both of these chapters are taken from the quantitative online questionnaire survey that gathered 340 responses. The data has been analysed using a number of statistical techniques including chi-square, regression analysis and the t-test. The way in which these are used are outlined in detail in the methods chapter.

As was previously mentioned the automotive sector is moving towards a transition from primarily petrol and diesel fuelled ICEVs to more sustainable PHEVs and BEVs (Poullikkas, 2015; Sierzchula et al., 2014). BEVs are often considered to be the most beneficial of these due to them having tailpipe zero emissions, high efficiencies and the potential to be fuelled entirely off renewable electricity (Helveston et al., 2014; Nordelöf et al., 2014; G. J. Offer et al., 2011; Schneiderei et al., 2015; Sierzchula et al., 2014; Thomas, 2009b). In order for these vehicles to have the greatest effect on improving urban air quality, reducing carbon emissions and reducing energy use they need to be deployed in larger numbers than they are at present. Therefore a greater

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<sup>4</sup> The results in this chapter are based on the publication Hardman, S., Shiu, E. & Steinberger-Wilckens, R., 2016. **Comparing High-End and Low-End Early Adopters of Battery Electric Vehicles**. *Transportation Research Part A: Policy and Practice*, 88, 40-57

understanding of how to increase market penetration needs to be developed, it is possible to achieve this through understanding early adopters of BEVs (Schuitema et al., 2013). This will lead to an understanding of where the market for these vehicles lies and also how to ensure that BEVs appeal to these markets. This will inform policy makers and automotive OEMs on how best to grow the market of BEVs such that the societal benefits can be maximised. At present the market is at a very early stage of development with recent market introductions beginning in 2008-2010. Since then the BEV market has developed and grown both in terms of the numbers of vehicles available and the numbers being adopted by consumers. At the end of 2014 there were 665,000 BEVs deployed globally, with the top three markets for BEVs being the US (39%), Japan (16%) and China (12%). The market shares of BEVs in these nations are still low and of these only in the US did BEVs achieve a 1% share of 2014 vehicle sales. The highest market shares in terms of yearly sales is in Norway (13%) and the Netherlands (4%) (IEA, 2015). These numbers are promising for an early market but are still insignificant compared to the entire transportation market (Rezvani et al., 2015), clearly greater effort is needed in order to increase these numbers.

A significant change in the landscape of the BEV market occurred in 2012 with the introduction of the Tesla Model S. Prior to this all BEVs on the market were what are considered here to be low-end electric vehicles (Hardman et al., 2014b, 2013). With the exception of the low volume Tesla Roadster, which was only available until 2012. These low-end vehicles all have prices of US\$30-40,000 and ranges of <100miles (Nissan, 2014). The Tesla Model S, which is considered here as a high-end BEV costs US\$70,000-105,000 and has a range of 270 miles (Tesla Motors Inc,

2014a). Therefore the introduction of this vehicle resulted in a new market segment being created. So far, within the literature, adopters of BEVs have been considered as one homogenous group, with studies overlooking potential differences between adopters of high and low-end BEVs.

At the beginning of this study it was hypothesised that the two groups adopting each BEV would be different. This is due to the significant differences in the price and features of the vehicles (Table 8.1). The adopters of low-end BEVs are referred to as 'low-end adopters' and the adopters of high-end BEVs 'high-end adopters'. It was believed that adopters would have different socio-economic and psychographic profiles. It was also believed that they would have differing opinions of their vehicles owing to their different attributes. Further to this, it was expected that future purchase intentions would be different, again due to the different attributes of the vehicles. This should be in relation to the attributes of each vehicle in order to understand what circumstances lead to a high likelihood of continued adoption. Consumer intent to purchase a BEV has been investigated in some detail within the literature (Bühler et al., 2014; Chorus et al., 2013; Koetse and Hoen, 2014; Sierzechula et al., 2014). These studies investigate the intent of ICEV drivers to adopt a BEV and not BEV driver's future intention to continue with BEV ownership. In order for the market to grow early adopters will be required to remain users of BEVs and make repeat purchases. Repeat purchases are more important than initial purchases in maintaining long term growth of any new product (Crawford and Benedetto, 2011; Rogers, 2003). The overriding aim of this chapter is to explore and understand the difference between adopters of low and high-end BEVs. This distinction between two different adopter groups of BEVs is the major contribution of this chapter. The hope is



that policy makers can use the results of this study to make more informed policy decisions and that OEMs are able to develop cars that are properly positioned for each market, in order to ultimately grow the BEV market.

Table 8.1: Comparison of the Nissan Leaf (low-end BEV), of which there are 152 in this study, and the Tesla Model S (high-end BEV), of which there are 153 in this study (Nissan, 2015; Tesla Motors Inc, 2015).

	<b>Nissan Leaf</b>	<b>Tesla Model S</b>
<b>Price</b>	US\$29,000-35,000	US\$70,000-105,000
<b>Range</b>	75 miles	270 miles
<b>Acceleration (0-60mph)</b>	9.9 seconds	3.1 seconds
<b>Top Speed</b>	93mph	155mph
<b>Fastest Charge Time (0-100%)</b>	4 hours	1 hour 15 minutes
<b>Electric motor</b>	80kW	515kW
<b>Battery</b>	24kWh	85kWh
<b>Length</b>	4.4m	4.9m
<b>Width</b>	1.7m	1.9m

BEV adoption research has been on going since the early 1990s (Golob et al., 1997; Kurani et al., 1994, 1996). Since then the body of literature has grown considerably with authors in many countries looking towards understanding the complexities of the issue. The vast majority of the literature gathers empirical data from persons who are not adopters of BEVs, often sampling the general public and asking them questions about BEV perceptions (Egbue and Long, 2012; Krupa et al., 2014; Plötz and Gnann, 2011; Plötz et al., 2014). Table 8.2 summarises the main BEV adoption literature and shows the authors, sample size, sample type (which includes whether they are actual adopters of BEVs or the general population for example) and shows the main conclusions of each study. Only recently has literature begun to report samples of people who have actual experience with BEVs. Studies that involve actual adopters of BEVs were outlined in the chapter 3, but include (Caperello et al., 2015; Lane et al., 2014; Tal and Nicholas, 2013; Tal, 2014; Turrentine et al., 2011). Whilst these

studies are becoming more numerous more studies are needed in order to guide the transition from ICEVs to BEVs.

Table 8.2: Summary of the main literature that explores BEV adoption, by author, sample size and sample type and the main conclusions of these studies that explore the expected socio-economic profile of BEV adopters and the expected benefits of BEVs.

Author(s)	Sample Size	Sample Type	Expected Socio-Economic Profile of Early Adopters	Expected Benefits of Battery Electric Vehicles
(Bühler et al., 2014)	79	German Mini E trial participants		Driving pleasure, low running costs, environmental
(Campbell, 2014b; Campbell et al., 2012)	413	General public	High income, high education, multi-car household, commuters	
(Caperello et al., 2015)	Not stated	General public and BEV adopters		Low running costs significant reason for adoption
(Carley et al., 2013b)	2302	General public	High education, own a hybrid, have environmental concerns	Fuel economy, environmental, technology
(Graham-Rowe et al., 2012)	40	7 day PHEV & BEV trial participants		Low running costs, environmental,
(Hidru et al., 2011)	3029	General public	Young, high education, high income	Performance, low running costs, environmental
(Kurani et al., 1994)		Households in California	Multi-Car households with a garage	
(Lane et al., 2014)	76	59 BEV owners and 17 BEV fleet users		Environmental, technology, low running costs, low maintenance, driving fun
(Peters and Dütschke, 2014)	92	92 BEV users in sample of 969 people with high interest in BEVs	Middle aged, male, multi-car households	Low running costs, environmental
(Plötz et al., 2014)	210	General public with high interest in BEVs	Middle aged, technical professions, rural or suburban multi-car households	
(Turrentine et al., 2011)	54	USA Mini E trial participants		Performance & handling, environmental, 1 foot driving

Currently within the literature there is no data that explores the future purchase intentions of current owners of BEVs. This data is important in order to understand the diffusion of BEVs through the market, and will also reveal if BEVs have enough benefits to convince adopters to continue with ownership. The majority of current BEV owners have purchased their vehicle as an initial purchase, having not owned a BEV previously. Subsequent purchases will be repeat purchases and it is known that the way in which an initial or repeat purchase decision are made is different (Crawford and Benedetto, 2011). One of the most significant limitations of the literature is that early adopters are considered to be one homogeneous group of consumers. They are referred to as having shared socio-economic and psychographic characteristics. No single study makes distinctions between different possible groups of early adopters. This is despite the price of BEVs ranging from US\$30,000 to US\$105,000 (Nissan, 2014; Tesla Motors Inc, 2014a). It is unlikely that an adopter of a US\$30,000 vehicle would be similar to the adopter of a US\$105,000 vehicle. Therefore this chapter addresses this major research gap; by identifying differences between high and low-end early adopters. This is achieved by understanding their socio-economic and psychographic characteristics; understanding how they respond to the vehicles that they have adopted and understanding their future BEV purchase intentions.

## **8.2 Results & Discussion**

The socio-economic profile of the 340 early adopters can be seen in Table 8.3. The sample is mostly male at 92.6%. Age is spread widely, but most are middle aged with 73.8% of the sample between 35-64 years of age. Level of education is high with

16.4% holding a doctorate or equivalent, 28.1% with a master's degree or equivalent and 40.6% with a bachelors or equivalent. This means that 85.1% of the sample has received a University level education. This is far higher than the entire population of the US where 32% over the age of 25 have achieved a University level degree. The level of income within the sample is high, with 76.5% earning more than US\$90,000 per year, the US average being US\$53,567 in 2014 (United States Census Bureau, 2015). The number of vehicles per household in this sample is 2.5, this is higher than the US average of 1.9 (US Department of Transportation, 2009). The sample consists of 359 BEVs; a breakdown of vehicles can be seen in Table 8.4. There are 19 more BEVs than respondents in this study as some owners have more than one BEV. The most common vehicles are the Tesla Model S (n=153) and the Nissan Leaf (n=152). The remaining vehicles are all fully electric cars with the exceptions of 2 electric motorcycles. Further to this there are 9 vehicles that are PHEVs; of these there are 2 BMW i3's and 7 Chevrolet Volt's/ Vauxhall Ampera's.

Table 8.3: Table showing the socio-economic profile for each group of adopters and a summary of all of the data within the sample. Income is shown in US income brackets and in US\$.

Sample Attributes		Low-end Total	(%)	High-end Total	(%)	Total	(%)
Gender	Male	177	95.7	138	89.0	315	92.6
	Female	8	4.3	17	11.0	25	7.4
Age	17-24	3	1.6	1	0.6	4	1.2
	25-34	30	16.2	9	5.8	39	11.5
	35-44	54	29.2	32	20.6	86	25.3
	45-54	45	24.3	43	27.7	88	25.9
	55-64	43	23.2	34	21.9	77	22.6
	65-74	9	4.9	27	17.4	36	10.6
	75-84	1	0.5	8	5.2	9	2.6
	85+	0	0.0	1	0.6	1	0.3
Education	Doctorate or Equivalent	18	10.0	37	23.9	55	16.4
	Masters or Equivalent	40	22.2	54	34.8	94	28.1
	Bachelors or Equivalent	84	46.7	52	33.5	136	40.6
	High School Diploma or Equivalent	31	17.2	11	7.1	42	12.5
	Other	7	3.9	1	0.6	8	2.4
Income	<\$10,000	1	0.5	2	1.3	3	0.9
	\$10,001-40,000	17	9.3	0	0.0	17	5.0
	\$40,001-90,000	51	28.0	8	5.2	59	17.5
	\$90,001-180,000	90	49.5	48	31.0	138	40.9
	\$180,000-400,000	23	12.6	70	45.2	93	27.6
	\$400,001+	0	0.0	27	17.4	27	8.0
Number of Cars in Household	1	22	11.9	19	12.3	41	12.1
	2	96	51.9	67	43.2	163	47.9
	3	45	24.3	39	25.2	84	24.7
	4	13	7.0	24	15.5	37	10.9
	5	9	4.9	6	3.9	15	4.4

Table 8.4: Breakdown of the BEVs in this study by make and model and the numbers of each vehicle in the study.

Make	Model	Count
BMW	i3	2
Citroën	C Zero	1
Fiat	500e	4
Ford	Focus EV	4
GM	Spark EV	1
GM/ Vauxhall	Volt/ Ampera	7
Mitsubishi	iMiEV	5
Nissan	Leaf	152
Renault	Zoe	6
Smart	Fortwo EV	3
Tesla	Model S	153
Tesla	Roadster	11
Toyota	Rav4 EV	7
Volkswagen	eGolf	1
Zero Motorcycles	S ZF11.4	2
Total		359

### 8.2.1 Socio-Economic Differences

Based on the results presented in Table 8.3 it does appear that the groups have different socio-economic attributes. However in order to define whether these are statistically significant differences the method of Chi-square was used. The results of this can be seen in Table 8.5. Firstly gender was compared, with the null hypothesis 'There is no difference in gender between high and low-end adopters'. This was rejected at a significance of 0.019. It is found that whilst both groups have a low number of females, high-end adopters are comprised of more females than low-end adopters. 11% of high-end adopters in this study were female, compared to only 4.3% of low-end adopters. There are however a low number of females in this study, only 25 in total. The age of adopters was compared using the null hypothesis 'There is no difference between high and low-end early adopters age'. This was rejected with a significance value of <0.001. It is found that high-end early adopters are of a higher age than low-end early adopters. The level of education was then compared

using the null hypothesis 'Level of education does not differ between high and low-end early adopters'. This null hypothesis was rejected with a significant value of  $<0.001$ . Meaning that there are differences in the level of education between high and low-end adopters. High-end adopters have a higher level of education than low-end adopters. 23.9% of high-end adopters hold a doctorate or equivalent compared to 10% for low-end adopters, and 34.8% of high-end adopters hold a masters or equivalent compared to 22.2% for low-end adopters. In total 92.3% of high-end adopters have received a University level education, compared to 78.9% of low-end adopters. The income of adopters was compared with the null hypothesis 'There is no difference between high and low-end early adopters level of income'. This hypothesis was rejected at a significance of  $<0.001$ . It is found that whilst both sets of adopters have a high income, the high-end adopters level of income is significantly higher than the low-end adopters. To illustrate this, 12.6% of low-end adopters earn more than US\$180,000 per year whilst 62.6% of high-end adopters earn more than this. The number of vehicles in the household does not differ between samples and the null hypothesis could not be rejected. Both household types have a higher car ownership than the US average (2.5 per household in this sample vs. 1.9 US average). In summary it is found that there is no difference in car ownership, but clear differences in gender, age, education and income, with average high-end adopters having higher socioeconomic status than low-end adopters.

Table 8.5: Results of Chi-square test comparing the significant difference of socio-economic variables between high and low-end early adopters.

Attribute	Chi-Square	df	Significance ( <i>p</i> )
Gender	5.464	1	0.019
Age	32.08	7	<0.001***
Education	28.495	4	<0.001***
Income	110.755	5	<0.001***
Number of Cars in Household	7.086	4	0.131

## 8.2.2 Psychographic Differences

In order to understand how high-end and low-end adopters' psychographic profiles differ, a number of questions measuring psychographic differences were investigated using the T-test. From this it appears that in general both groups of adopters are typical early adopters based on the data presented in Table 8.6, however there are some differences. When comparing each group the null hypothesis was rejected for 2 questions. These were 'The level of empathy does not differ between high-end and low-end adopters' and 'There is no difference in the length of the innovation decision period between high and low-end adopters'. It is found that high-end adopters have a significantly higher level of empathy, and that they often take less time before making a decision to invest in a new technology. In Rogers' theory (Rogers, 2003) it is stated that these are common traits of early adopters. Therefore it appears that within this sample, high-end adopters are more representative of early adopters. In addition to these differences there is one variable with a significance of <0.1 and a further two that are close to 0.1. These numbers are not low enough for the null hypotheses to be rejected but they do indicate a number of additional subtle differences. All of the differences suggest that high-end adopters are more aligned with Rogers' theory, being more representative of typical early adopters compared to low-end adopters.



Table 8.6: T-test results of the comparison between psychographic variables between high-end and low-end early adopters (Likert scale for questions is 1=Agree Strongly, 2=Agree Slightly, 3= Neither Agree or Disagree, 4= Slightly Disagree, 5= Strongly Disagree).

Question	Adopter Group	N	Mean	Std. Deviation	Std. Error Mean	T-test for equality of means
						Sig. (2-tailed)
You regularly participate in social activity	High-end	155	2.13	1.067	0.086	0.518
	Low-end	185	2.05	1.062	0.078	
You regularly interact with people in your local community	High-end	155	2.19	1.057	0.085	0.524
	Low-end	182	2.27	1.117	0.083	
You are often involved in matters that require you to interact with people outside of your local network	High-end	154	2.35	1.169	0.094	0.352
	Low-end	183	2.47	1.171	0.087	
You have a small network of people you know	High-end	151	2.66	1.255	0.102	0.131
	Low-end	183	2.45	1.239	0.092	
People you know are often influential when you are considering buying or trying a new technology	High-end	153	2.95	1.21	0.098	0.18
	Low-end	182	3.13	1.2	0.089	
You are often good at understanding peoples feelings	High-end	154	2.1	0.955	0.077	0.024*
	Low-end	184	2.35	1.071	0.079	
You are often contemplative when you are making a decision	High-end	153	1.68	0.908	0.073	0.959
	Low-end	184	1.68	0.892	0.066	
You are often reluctant to change your routine	High-end	155	3.05	1.224	0.098	0.112
	Low-end	185	2.84	1.09	0.08	
You want to be among the first people to try a new technology	High-end	155	2.32	1.024	0.082	0.237
	Low-end	185	2.18	1.026	0.075	
You invest in new technologies soon after they become available for purchase	High-end	154	2.53	1.184	0.095	0.973
	Low-end	184	2.52	1.106	0.082	
Friends will often use you as a point of reference for new technologies	High-end	155	2.23	1.165	0.094	0.136
	Low-end	185	2.04	1.067	0.078	
You often take your time before making a decision to invest in a new technology	High-end	155	2.01	0.929	0.075	0.001***
	Low-end	184	1.7	0.82	0.06	
You are often sceptical about new technologies	High-end	153	3.04	1.088	0.088	0.851
	Low-end	184	3.02	1.138	0.084	
You tend to invest in new technology once you have been convinced about the benefits of using it	High-end	152	1.78	0.891	0.072	0.772
	Low-end	184	1.76	0.83	0.061	
You rarely invest in new technologies	High-end	154	4.12	1.037	0.084	0.312
	Low-end	185	4.23	0.924	0.068	
You prefer to stick to existing technologies that you are familiar with	High-end	151	3.72	1.027	0.084	0.305
	Low-end	182	3.84	0.972	0.072	
You would consider yourself willing to take a risk when it comes to investing in new technologies	High-end	152	2.05	0.833	0.068	0.604
	Low-end	183	2	0.777	0.057	
Uncertainty of the success of a technology in the long-term makes you feel uncomfortable about investing in it	High-end	152	3.2	1.01	0.082	0.093
	Low-end	184	3	1.136	0.084	
You keep up to date with what is happening in the media	High-end	155	1.45	0.749	0.06	0.566
	Low-end	185	1.5	0.708	0.052	
You often listen to the views of experts on matters that are important to you	High-end	153	1.73	0.896	0.072	0.16
	Low-end	185	1.87	0.9	0.066	

### 8.2.3 Battery Electric Vehicle Attributes

In order to understand how respondents view their vehicles they were asked, 'Considering each of the following attributes how do you think your electric vehicle compares to an internal combustion engine vehicle?' The list of attributes given can be seen in Figure 8.1 & Table 8.7. Respondents were given 5 answer options on a semantic differential scale. These were Far Superior, Slightly Superior, Similar, Slightly Worse and Far Worse. Figure 8.1 shows a summary of how adopters view their vehicles in comparison with ICEVs. The scale of the spider diagram starts at 'Far Worse' in the centre goes through 'Similar' and to 'Far Superior' on the outermost edge of the decagon. The graph shows that high-end adopters view their vehicles as being superior in the 7 following areas; brand, vehicle image/looks, vehicle performance, fuel economy, environmental impacts, lifestyle fit and running costs. This adopter group viewed purchase price, time to refuel and vehicle range as similar to ICEVs. Low-end adopters viewed their vehicles as being superior in the 5 following areas; performance, environmental impacts, fuel economy, lifestyle fit, and running costs. They viewed the vehicles as having similar vehicle image/looks and brand and as having worse purchase price, vehicle range and time to refuel.

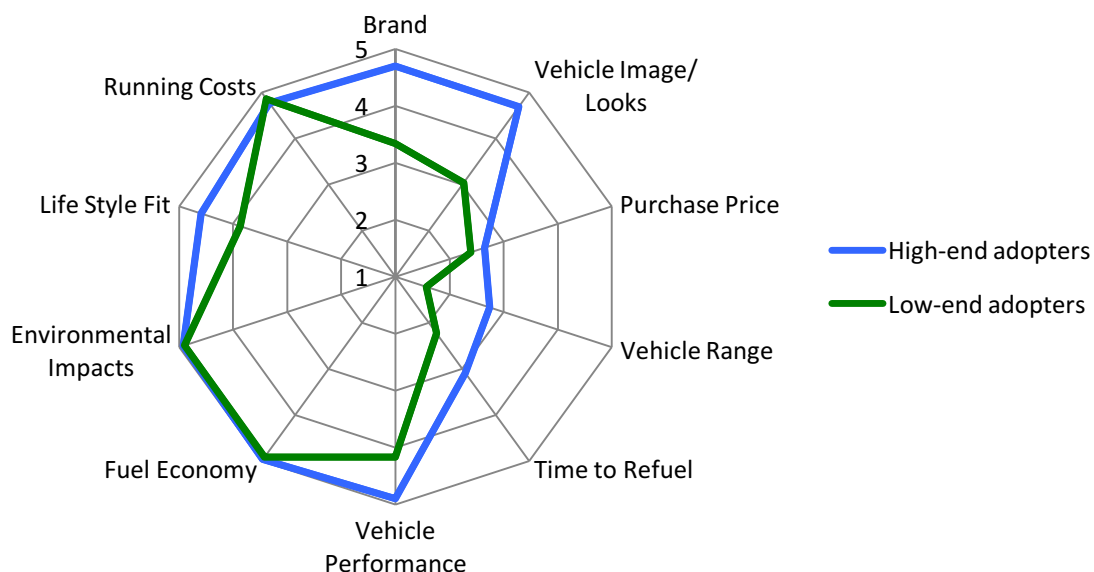


Figure 8.1: Spider diagram showing differences in answers to the question 'Considering each of the following vehicle attributes how do you believe your electric vehicle compares to an internal combustion engine vehicle?' With answers on a Likert scale of 5= Far Superior, 4= Slightly Superior, 3= Similar, 2= Slightly Worse, 1= Far Worse\*. This means the closer the line to the outer edge the more superior adopters perceive this attribute.

(\*Note that the Likert scale in this figure has been changed from the format of the raw data which is 1= Far Superior, 2= Slightly Superior, 3= Similar, 4= Slightly Worse, 5= Far Worse in order to improve the readability of the figure.)

In order to understand how each adopter group's opinions compare, the T-test was applied to the questions that measure how early adopters view their vehicles. The results of the T-tests can be seen in Table 8.7. The null hypothesis 'there is no difference between perceptions of brand between high-end and low-end early adopters' was rejected at a significance of  $<0.001$ . High-end adopters find their vehicles to have a superior brand compared to ICEVs whilst low-end adopters believed their vehicles to have a similar brand. The null hypothesis for vehicle image

‘there is no difference between perceptions of vehicle image between high and low-end early adopters’ was rejected at a significance of  $<0.001$ . High-end adopters view their vehicles as having a superior image and low-end adopters find their vehicles to be similar to ICEVs. The null hypothesis for purchase price was also rejected, this time at a significance of 0.028. It is found that high-end adopters view the purchase price of their vehicles as similar to ICEVs, whilst owners of low-end BEVs view their vehicles as slightly worse in terms of purchase price. The null hypothesis comparing the means for vehicle range was rejected at a significance of  $<0.001$ . High-end early adopters believed that their vehicles have a similar range as compared to ICEVs. Low-end adopters believed their vehicle’s range was worse than that of a comparable ICEV. This result is unsurprising as the EPA estimated range of a Tesla BEV is 270 miles, whilst the range of a low-end BEV is usually less than 100 miles.

The null hypothesis ‘there is no difference in how high and low-end adopters perceive their vehicles time to refuel compared to that of an ICEV’ was rejected. This was rejected at a high level of significance of  $<0.001$ . It is found that high-end adopters believe their vehicles have similar time to refuel as ICEVs, low-end adopters believe their vehicles to have worse time to refuel than ICEVs. It is surprising that high-end adopters perceive their vehicles to have similar time to refuel compared to ICEVs. The time to fully recharge a Tesla BEV is far longer than it takes to fill an ICEV with petrol or diesel. However the amount of time required for human interaction with the vehicle is similar, meaning that plugging in a BEV takes no longer than inserting a petrol or diesel pump into an ICEV. Additionally as is shown below and is discussed in detail in chapter 10 with qualitative evidence from early adopters, some adopters viewed BEVs as being more convenient to refuel/recharge.

The null hypothesis comparing the means for performance was rejected at a significance of  $<0.001$ . Both groups of adopters believed their BEVs were superior to ICEVs in this respect, however, high-end adopters viewed their vehicles as far superior, with low-end adopters viewing their vehicles as only slightly superior. The null hypothesis 'there is no difference between high and low-end adopters' perception of their vehicles' life style fit compared to ICEVs' was rejected at a significance of  $<0.001$ . Both groups of adopters believe their vehicles to be a better life style fit compared to ICEVs, however, high-end adopters found their vehicles to be a better fit than did the low-end adopters. The null hypotheses comparing fuel economy, running costs and environmental impact could not be rejected. There is no difference in how high and low-end adopters view these attributes. Both groups believe that their vehicles are superior to ICEVs in these three areas. Indeed BEVs do have superior fuel economy, running costs and environmental impacts compared to ICEVs. Out of 10 vehicle attributes tested, 7 null hypotheses can be rejected. This along with Figure 8.1 clearly shows that each adopter group responses to their vehicle are significantly different. High-end adopters are found to have more positive opinions of their vehicles compared to low-end adopters; they believe their vehicles are superior compared ICEVs.

Table 8.7: Table showing differences in answers to the question ‘Considering each of the following vehicle attributes how do you believe your electric vehicle compares to an internal combustion engine vehicle?’ Answers were measured using a Likert scale (1=Far Superior, 2=Slightly Superior, 3= Similar, 4= Slightly Worse, 5= Far Worse).

						T-test for equality of means
Attribute	Adopter Group	N	Mean	Std. Deviation	Std. Error Mean	Sig. (2-tailed)
Brand	High-end	155	1.3	0.616	0.049	<0.001***
	Low-end	185	2.66	0.833	0.061	
Vehicle Image/ Looks	High-end	154	1.31	0.566	0.046	<0.001***
	Low-end	185	2.96	0.983	0.072	
Purchase Price	High-end	153	3.35	1.115	0.09	0.028*
	Low-end	183	3.61	0.994	0.073	
Vehicle Range	High-end	155	3.26	1.05	0.084	<0.001***
	Low-end	185	4.43	0.818	0.06	
Time to Refuel	High-end	152	2.91	1.439	0.117	<0.001***
	Low-end	183	3.77	1.315	0.097	
Vehicle Performance (Acceleration, Top Speed)	High-end	155	1.1	0.444	0.036	<0.001***
	Low-end	184	1.83	0.842	0.062	
Fuel Economy	High-end	154	1.03	0.211	0.017	0.189
	Low-end	185	1.08	0.416	0.031	
Environmental Impacts	High-end	155	1.08	0.37	0.03	0.633
	Low-end	185	1.1	0.392	0.029	
Life Style Fit	High-end	155	1.41	0.737	0.059	<0.001***
	Low-end	183	2.13	0.946	0.07	
Running Costs	High-end	154	1.23	0.581	0.047	0.095
	Low-end	184	1.14	0.433	0.032	

Further to the attributes that were tested, respondents were also able to provide qualitative feedback with the question ‘Please use the space below to list any advantages you think you (or your household) has experienced by using an electric vehicle?’ This question revealed an additional benefit of BEV ownership. Without any prior cues 88 respondents (25.8%) said that BEV recharging had added convenience over ICEV refuelling. Respondents reported that this saved them time and was more convenient for them. Respondent No. 8 answered, *“Not having to waste time to go to gas stations”*, and No. 44 responded *“Save Time by never going to the gas station”*.

Both high and low-end adopters mentioned this as a benefit to BEV ownership. However, a larger proportion of high-end adopters mentioned this as a benefit, with 37.9% as compared to only 18.8% of low-end adopters. Figure 8.1 and Table 8.7 show that high-end adopters view time to refuel more preferentially than low-end adopters. This difference may be due to high-end BEVs having a longer range and a shorter recharge time, which means that when charging more range is added in less time compared to the low-end vehicles. Additionally due to the longer range owners of high-end vehicles will be less likely to charge away from home and they will have to charge less often. This topic is explored in more detail in chapter 10 with evidence from the 39 in-depth interviews.

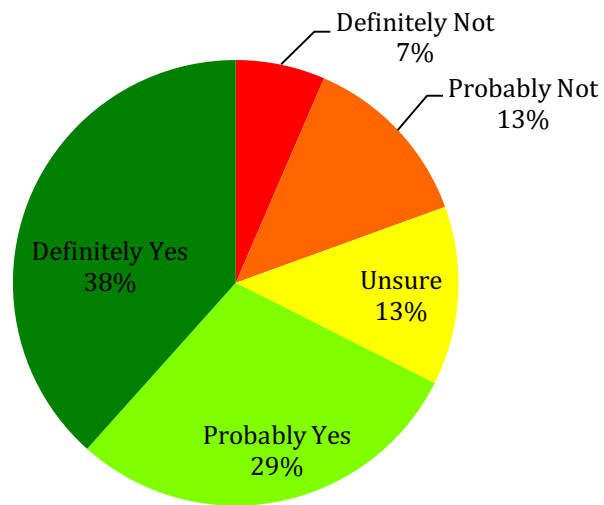
#### **8.2.4 Differences in Future Purchase Intentions**

The way in which early adopters perceive the attributes of their vehicles will have an implication on the likelihood of repeat purchases. Two questions measured respondent's future vehicle choices. The first asked 'Will the next car be another battery electric vehicle?' With the following scale for answers 'Definitely Not', 'Probably Not', 'Unsure', 'Probably Yes' and 'Definitely Yes'. The results of this can be seen in Figure 8.2. The second asked 'Will your next car be another Tesla?' or 'Will your next car be another vehicle of the same manufacturer as your current vehicle?' The possible answers for this were 'Yes', 'No' or 'Don't Know'. The results of this can be seen in Figure 8.3. Results from the first question (which used the Likert scale) were compared using the T-test to compare the means; the null hypothesis of there being no difference between the two groups was rejected at a significance of  $<0.001$  for both questions. It was found that high-end adopters have a

higher intent to continue with BEV ownership, and it is likely that they will continue to own a Tesla with their next BEV. 67% of low-end adopters would probably or definitely continue with BEV ownership, compared to 81% of high-end adopters. Of the high-end adopters 59% said they would continue with Tesla ownership. Of the low-end adopters only 23% said they would continue with the same make of BEV. These findings are shown in Figure 2 and 3. This demonstrates that low-end adopters are less likely to continue with BEV ownership than high-end adopters. This is concerning for the diffusion of BEVs through the market. This lack of willingness to continue with BEV ownership is not 'technological rejection' as Rogers defines this as *'The decision to not adopt an innovation'*. Within diffusion literature the decision to not continue with the adoption of an innovation is known as discontinuance. Discontinuance has previously been explored in the field of assistive technology for disabled persons (Philips and Zhao, 1993; Scherer, 1996). It has not received attention within automotive literature, and needs to be further understood.



**Low-end adopters**  
Will your next vehicle be another battery electric vehicle?



**High-end adopters**  
Will your next vehicle be another battery electric vehicle?

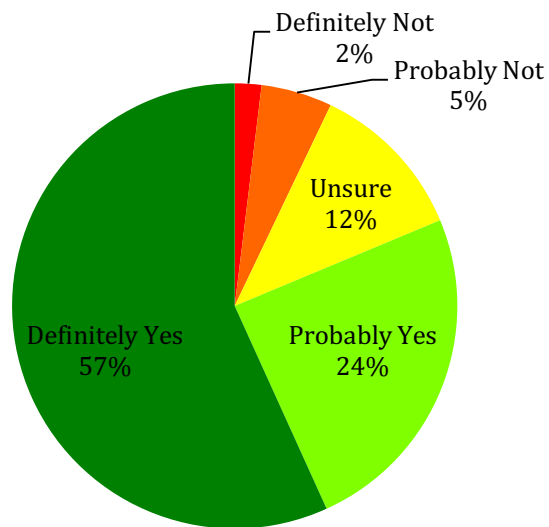
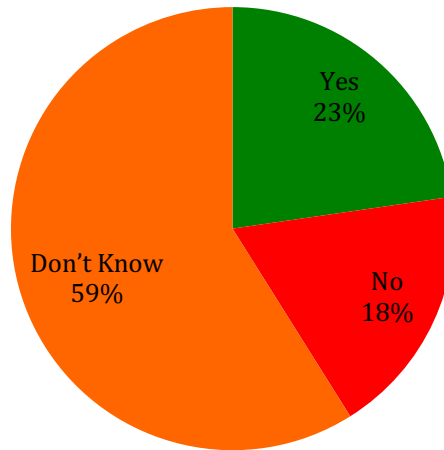


Figure 8.2: Comparison of future purchase intentions of BEVs between low-end and high-end adopters (n=340).

#### Low-end adopters

Will your next vehicle be an electric vehicle from the same manufacturer as your current vehicle?



#### High-end adopters

Will your next vehicle be another Tesla?

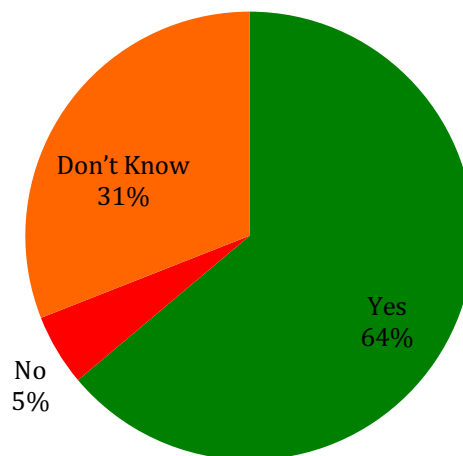


Figure 8.3: Comparison between low-end and high-end adopters regarding their future intention to purchase a BEV of the same make as their current electric vehicle (n=340).

### 8.2.5 Understanding Differences in Future Purchase Intentions

In order to build a greater understanding of why some adopters may not continue with BEV ownership multiple regression was used to understand how the results from the question 'Will the next car be another battery electric vehicle?' compare with how owners perceive the attributes of their vehicles (Table 8.7). This enables identification of which attributes of BEVs are a good indicator of likelihood of continuing with BEV ownership.

The first multiple regression model for low-end adopters had an ANOVA of  $<0.001$  suggesting that the independent variables were a good predictor of the dependent variable. When comparing the significance values for each independent variable the null hypothesis was rejected for 6 attributes. These were vehicle image/looks, purchase price, time to refuel, environmental impacts, life style fit and running costs. Therefore these 6 attributes were tested again. The attributes that had a significance value of more than 0.1 were omitted from this regression analysis. The results of this can be seen in Table 8.8. The ANOVA significance value for this was  $<0.001$  suggesting a high level of significance for the model. This shows that time to refuel, environmental impacts and running costs are the best predictors of future intent to own a BEV for low-end adopters. In order to confirm that these 3 attributes were the most significant contributors to willingness to continue with BEV ownership one final regression was done. This time only time to refuel, environmental impacts and running costs were included. The ANOVA value was  $<0.001$  and the values for each of the three attributes were all less than 0.05 suggesting that they are indeed excellent predictors of willingness to continue with BEV ownership. The beta values

for time to refuel is 0.198, environmental impacts 0.201 and running costs 0.173. This means that for every 1 unit increase on the Likert scale measuring opinions of environmental impacts there will be a 0.201 unit increase in willingness to continue with BEV ownership. This rate of increase is slightly higher than the other two significant variables, suggesting that environmental impacts are the most significant contributor to likelihood to continue with BEV ownership into the future for low-end adopters. The results from this can be seen in Table 8.9.

Table 8.8: Linear regression results for low-end adopters comparing future purchase intentions as the dependent variable with answers to ‘Considering each of the following vehicle attributes how do you believe your electric vehicle compares to an internal combustion engine vehicle?’ as the independent variables. Note that Beta values are negative due to the reverse coding of the Likert scale for the independent variable.

Independent Variables	Unstandardised Coefficients		Standardised Coefficients		Sig.
	B	Std. Error	Beta	t	
Vehicle Image/Looks	0.113	0.092	0.09	1.23	0.22
Brand	-0.14	0.098	-0.111	-1.432	0.154
Time to Refuel	-0.151	0.071	-0.157	-2.131	0.035*
Environmental Impacts	-0.714	0.265	-0.206	-2.699	0.008**
Life Style Fit	-0.149	0.1	-0.112	-1.485	0.139
Running Costs	-0.378	0.227	-0.128	-1.669	0.097
Dependent Variable: Will your next vehicle be another battery electric vehicle? Likert Scale 1=Definitely Not, 2= Probably Not, 3= Unsure, 4= Probably Yes, 5= Definitely Yes					

Table 8.9: Final linear regression results for low-end adopters comparing future purchase intentions as the dependent variable with answers to ‘Considering each of the following vehicle attributes how do you believe your electric vehicle compares to an internal combustion engine vehicle?’ as the independent variable. Note that Beta values are negative due to the reverse coding of the Likert scale for the independent variable.

Independent Variables	Unstandardised Coefficients		Standardised Coefficients		
	B	Std. Error	Beta	t	Sig.
<b>Time to Refuel</b>	-0.189	0.067	-0.198	-2.814	0.005**
<b>Environmental Impacts</b>	-0.651	0.243	-0.201	-2.677	0.008**
<b>Running Costs</b>	-0.508	0.219	-0.173	-2.319	0.022*
Dependent Variable: Will your next vehicle be another battery electric vehicle? Likert Scale 1=Definitely Not, 2= Probably Not, 3= Unsure, 4= Probably Yes, 5= Definitely Yes					

The same procedure was carried out for high-end adopters. Linear regression was applied to all 10 attributes as the independent variables against the dependent variable ‘Will the next car be another battery electric vehicle?’ The ANOVA significance value for this was 0.025 suggesting the model does have explanatory power. The first regression analysis allowed the null hypothesis for time to refuel, fuel economy, environmental impacts and running costs to be rejected. These 4 attributes were further tested in the absence of the 6 attributes whose significance value was more than 0.1. The ANOVA value for this linear regression was <0.001 suggesting that the model is significant. For these results the null hypothesis was rejected for time to refuel, fuel economy and running costs (Table 8.1). A second multiple regression was run with only these three attributes. This can be seen in Table 8.11, this model again had an ANOVA value of <0.001 suggesting the model is significant. In this multiple regression analysis time to refuel and running costs are the most significant contributors to likelihood to continue with BEV ownership into the future. In order to conclusively state that these two attributes are statistically significant a final regression model was run (Table 8.12), this again had an ANOVA of <0.001 and both

independent variables were  $<0.1$ . Of these two attributes time to refuel had a Beta value of 0.153 and running costs 0.271. This suggests that for high-end adopters running costs are the most significant contributor to likelihood to continue with BEV ownership in future vehicle choices. Therefore due to the low running costs of a Tesla BEV willingness to continue with ownership is high.

Table 8.10: Linear regression results for high-end adopters comparing future purchase intentions as the dependent variable with answers to 'Considering each of the following vehicle attributes how do you believe your electric vehicle compares to an internal combustion engine vehicle?' as the independent variable. Note that Beta values are negative due to the reverse coding of the Likert scale for the independent variable.

Independent Variables	Unstandardised Coefficients		Standardised Coefficients		
	B	Std. Error	Beta	t	Sig.
Time to Refuel	-0.112	0.053	-0.164	-2.098	0.038*
Fuel Economy	-0.73	0.416	-0.159	-1.755	0.081
Environmental Impacts	0.327	0.231	0.125	1.42	0.158
Running Costs	-0.417	0.139	-0.248	-3	0.003**
Dependent Variable: Will your next vehicle be another battery electric vehicle? Likert Scale 1=Definitely Not, 2= Probably Not, 3= Unsure, 4= Probably Yes, 5= Definitely Yes					

Table 8.11: Third linear regression results for high-end adopters comparing future purchase intentions as the dependent variable with answers to 'Considering each of the following vehicle attributes how do you believe your electric vehicle compares to an internal combustion engine vehicle?' as the independent variable. Note that Beta values are negative due to the reverse coding of the Likert scale for the independent variable.

Independent Variables	Unstandardised Coefficients		Standardised Coefficients		
	B	Std. Error	Beta	t	Sig.
Time to Refuel	-0.108	0.053	-0.158	-2.016	0.046*
Fuel Economy	-0.475	0.376	-0.103	-1.262	0.209
Running Costs	-0.401	0.139	-0.238	-2.885	0.005**
Dependent Variable: Will your next vehicle be another battery electric vehicle? Likert Scale 1=Definitely Not, 2= Probably Not, 3= Unsure, 4= Probably Yes, 5= Definitely Yes					

Table 8.12: Final linear regression results for high-end adopters comparing future purchase intentions as the dependent variable with answers to 'Considering each of the following vehicle attributes how do you believe your electric vehicle compares to an internal combustion engine vehicle?' as the independent variable.

Note that Beta values are negative due to the reverse coding of the Likert scale for the independent variable.

Independent Variables	Unstandardised Coefficients		Standardised Coefficients		
	B	Std. Error	Beta	t	Sig.
Time to Refuel	-0.104	0.053	-0.153	-1.952	0.053
Running Costs	-0.446	0.132	-0.271	-3.455	0.001***
Dependent Variable: Will your next vehicle be another battery electric vehicle? Likert Scale 1=Definitely Not, 2= Probably Not, 3= Unsure, 4= Probably Yes, 5= Definitely Not					

Multiple regression analysis suggests that for low-end adopters time to refuel, environmental impacts, and running costs are the best predictors of future intention to adopt. This suggests that these consumers are both motivated by functional considerations but also a social or emotional desire due to their environmental concern. Of these three attributes the beta value is highest for environmental impacts, suggesting that this is the best predictor of future likelihood to continue with BEV adoption. For high-end adopters time to refuel and running costs are the two best predictors of future intention to adopt, suggesting that high-end adopters are more motivated by functional considerations than a social or emotional desire to adopt. Further to this for high-end adopters running costs has the strongest correlation to likelihood to continue with BEV ownership with a beta value of -0.238. Low-end adopters view running costs and environmental impacts as superior and these attributes do contribute to increased propensity to adopt. The third attribute to be found as a good predictor of willingness to continue with BEV ownership, for low-end adopters, was time to refuel. However, long recharge times mean that time to refuel is viewed as inferior compared to ICEVs and therefore this is a potential barrier

to low-end adopters' willingness to continue with BEV ownership in the future. Therefore long recharge times are the most significant contributor to discontinuance by low-end adopters. The model suggests that if this attribute, or perceptions it can be improved, willingness to continue with BEV ownership will increase. Therefore in future generations of low-end BEVs, recharge times should be significantly improved over current generations of the vehicles.

### **8.3 Conclusion**

Based on data from 340 early adopters of BEVs it has been possible to corroborate a number of assumptions previously made within the literature. In this sample it was found that early adopters have high-incomes, with 76.5% earning more than US\$90,000 per year, this is in agreement with (Hidrué et al., 2011). Early adopters are also highly educated with 85.1% having achieved a university level qualification, agreeing with (Campbell, 2014a; Campbell et al., 2012). They are mostly male (92.6%) something which was suggested by (Plötz et al., 2014). In this sample, of mainly US citizens, car ownership was higher than the US national average of 1.9 per household, with each household having 2.5 cars on average. This is in agreement with (Kurani et al., 1996; Plötz et al., 2014). Finally it was found that 25.3% had owned a hybrid vehicle prior to BEV ownership; whilst this is higher than average it suggests that hybrid ownership is not a prerequisite for BEV ownership, therefore the assumption by Carley et al (Carley et al., 2013b) only partially holds true. In this sample there was no clear trend in terms of the age of respondents, however they are mostly between 35-65 (76.5%) years old suggesting that BEVs



may be most popular with people who are around middle aged. This may be related to household income but is not further analysed here.

Previous literature overlooked the possibility of there being different groups of adopters. However, results from this investigation reveal two distinct groups, which are referred to here as low-end adopters and high-end adopters. The groups have significantly different socio-economic profiles, with high-end adopters being of higher income, higher education and of higher age. Both groups still align with the assumptions made in the literature (Campbell, 2014a; Hidrue et al., 2011; Kurani et al., 1996; Plötz et al., 2014), however high-end adopters have a far higher socio-economic status compared to low-end adopters. Two statistically significant psychographic differences were identified, with high-end adopters having greater empathy and taking less time to adopt a new technology. These two differences add to the evidence suggesting that both groups of adopters are not homogenous.

It was found that compared to ICEVs, BEVs have beneficial performance, running costs, life style fit, environmental impacts and fuel economy. This is in agreement with (Lane et al., 2014; Turrentine et al., 2011) who found performance to be a benefit, but goes against some suggestions that the performance of a BEV is viewed negatively compared to ICEVs (Schuitema et al., 2013). This results agrees with (Lane et al., 2014), who found running costs to be a benefit and (Carley et al., 2013b; Lane et al., 2014) who suggest environmental impacts and fuel economy would be benefits of BEV ownership. High-end adopters also found image and brand to be a benefit. Image has previously been suggested as a benefit by (Carley et al., 2013b). Despite both adopter groups agreeing that running costs, lifestyle fit, environmental impacts, fuel economy and performance are superior, there are still statistically

significant differences in the way in which each group view these attributes. It was found that high-end adopters view their vehicles more preferentially than low-end adopters in these areas. High-end adopters did not believe their vehicles were worse than ICEVs in any area measured, but low-end adopters believed their vehicles had worse range, time to refuel and purchase price compared to an ICEV.

This chapter adds further to the literature by measuring future purchase intentions of BEV owners. It was found that each adopter group has different future purchase intentions. High-end adopters appear likely to continue with BEV ownership with 81% intending to continue with BEV ownership in future purchases. Brand loyalty was also high with 64% stating their next vehicle will be the same make as their current vehicle. Low-end adopters are less likely to continue with BEV ownership with 67% likely to continue with owning a BEV, furthermore; only 23% will continue owning a BEV of the same make as their current model. Therefore one third of low-end adopters may abandon the technology with their next vehicle purchase, and 77% will choose a vehicle of a different brand, this could be harmful for the diffusion of BEVs and the creation of a more electrified transportation system.

It was found that low-end adopter's future purchase intentions are significantly correlated to opinions on their vehicles and that time to refuel, environmental impacts and running costs are the most significant influences. Low-end adopters' opinions of environmental impacts and running costs were positive. Their opinions of time to refuel however were negative, as they believed that this attribute was slightly or far worse than an ICEV.

### **8.3.1 Policy and Managerial Implications**

The results from this chapter can be used to make a number of policy and managerial implications. Even though the results presented here are representative of early adopters in the United States the data may be applicable to other markets globally. It has been previously suggested that early adopters of BEVs will be similar regardless of geographic location due to their similar socio-economic characteristics, and also because diffusion processes are the same in different markets (Schneidereit et al., 2015). Therefore in markets where BEVs have little market share policy makers and OEMs can seek to target persons with similar socio-economic characteristics as the early adopters of this chapter.

This chapter has shown that there are two distinct BEV adopter groups. Therefore when introducing and promoting BEVs to markets, policy makers and OEMs should not view early adopters as one homogenous group. The results show that each group has a different socio-economic and psychographic profile. They respond to their vehicles differently and they have different future purchase intentions. When OEMs and policy makers are promoting either high or low-end BEVs they should target the correct markets for each vehicle. The vehicle should address the right demographics, and should have the right attributes. For example low-end adopters appear to be more motivated by environmental reasons compared to high-end adopters, therefore this attribute should be promoted in low-end vehicles, not so much for high-end vehicles.

A second implication of this chapter is that it reports that close to a third of all low-end adopters may discontinue with BEV ownership in future purchases. Low-end BEVs

have more shortcomings and therefore adopters may require more support to be convinced to accept the vehicles. Low-end adopters also have a lower socio-economic profile with lower incomes meaning high costs may be more of a barrier. The results from this chapter suggest the primary reason for this discontinuance is due to the long recharge times of low-end BEVs. This behaviour will be damaging to the BEV market and therefore a joint effort by policy makers and OEMs will be needed to encourage low-end adopters to continue with their adoption decision. In order to prevent this from occurring OEMs should concentrate efforts on reducing recharge times of their BEVs. Clearly time to refuel is also linked to range, and if vehicles have longer ranges fewer charging events are required, therefore increasing range may also change opinions of time to refuel. Of all the attributes, low-end adopters viewed range the most negative, and therefore this attribute should also be improved. Policy makers will need to continually support the low-end of the BEV market, perhaps more than the high-end, in order to prevent early adopters from abandoning BEVs.

Thirdly, automotive OEMs producing low-end BEVs may wish to look at the results presented in this chapter for high-end BEVs. These results may help to inform OEMs how to improve the perceptions of their vehicles, and which vehicle attributes they should improve. If OEMs producing low-end BEVs can produce a BEV that is perceived by consumers as being similar to a high-end BEVs, especially for refuelling time and range, then rates of adoption may increase and discontinuance may not occur. As previously mentioned, the priority will be increasing range and reducing refuelling time, but it will also be beneficial to improve performance, perceptions of brand and the vehicles image/looks.

### **8.3.2 Limitations**

The results in this chapter are all taken from an online questionnaire survey meaning they will be influenced by a sample bias. A significant bias will be due to the way in which the survey was administered and will mean that BEV adopters who do not use online forums will be missed. In order to counteract the bias due to respondents being only recruited online the results of the survey were compared to an unpublished survey conducted by UC Davis. Survey respondents in that study were recruited via post once they had purchased a BEV. Respondents could respond online, over the phone or via post. This means that the results of this study will be less effected by a sample bias. The survey has to date gathered 10,000 responses from BEV adopters. The socio-economic results from this chapter were informally compared to the results from the UC Davis survey. It was found that the sample in each survey had similar socio-economic profiles. This leads us to believe that the results in this chapter are still representative of early adopters of BEVs.

# CHAPTER 9

Exploring the premium paid for battery electric vehicles

## **Chapter 9 Exploring the premium paid for battery electric vehicles**

### **9.1 Introduction**

The objective of this chapter is to quantify the price premium paid for a BEV. In most cases, consumers will be required to pay a higher than conventional market price if they are to adopt a BEV or any other new AFV, which includes FCVs. This can be considered a 'premium' on top of the current market price. However, it is not well understood what premium early adopters are willing to pay. Current literature does not use data from actual adopters of BEVs, rather it asks potential adopters what they would be willing to pay for a BEV compared to an ICEV (Hidrué et al., 2011; Potoglou and Kanaroglou, 2007). It is well established within the literature that attitudinal or predictive data is not representative of consumers' actual behaviour (Bamossy and Solomon, 2013; Lane and Potter, 2007). Therefore there is a need to quantify what price premium has actually been paid with empirical evidence from early adopters who have transitioned from ICEV to BEV ownership. This chapter aims to follow on from previous studies and record what premium early adopters might pay for a BEV compared to an ICEV. From the data presented it is clear that some consumers are willing to pay a significant premium for BEVs. This is the first study to use behavioural data rather than attitudinal data for studying the difference in price paid for a BEV. The data in this chapter is from the online questionnaire survey of 340 BEV adopters. The results in this chapter show the difference in price paid for a BEV that they currently own and an ICEV that they would normally of purchased had they not adopted there BEV. Therefor the result assume that in the

hypothetical case that a BEV was not adopted consumers would have continued to own the same ICEV as they had previously.

This chapter uses data taken from the same questionnaire survey as chapter 8. That chapter and a previous paper found these adopters to be different in a number of ways (Hardman et al., 2016). As the results in this chapter will show, these two groups of adopters also have paid different premiums for their BEVs, with one group paying significantly more for a BEV compared to their previous vehicle than the other group, this being the major finding of chapter 9.

BEVs have beneficial attributes when compared to ICEVs. As a new technology this comes at a cost, namely high prices for early generations of products entering the market. The reasons for this are initially low numbers produced and the necessity for OEMs to reclaim at least a part of the development costs during this phase of market entry. Therefore early adopters will be required to pay a price premium to access the novel technology at this early stage of the market. Previous studies have found that consumers are willing to pay a premium for a BEV, this was discussed in the literature review chapter. The existing literature suggests that consumers would be willing to pay US\$0-16,500 more for a BEV compared to an ICEV (Hidrué et al., 2011; Kurani et al., 1996; Larson et al., 2014; Potoglou and Kanaroglou, 2007; Turrentine and Kurani, 2007). All of these studies reached their conclusions without empirical evidence from early adopters.

## **9.2 Results & Discussion**

High-end adopters are owners of Tesla BEVs, which cost US\$70,000-105,000. Low-end adopters are owners of BEVs such as the Nissan Leaf and Fiat 500e, which cost



US\$23,845-42,400. In chapter 8 it was found that these two groups have significantly different socio-economic and psychographic profiles. Further to this, they have differing opinions on the attributes of their vehicles. High-end adopters perceive their vehicles more preferentially than low-end adopters do. Finally it was found that high-end adopters are more likely to continue with BEV ownership in their future vehicle choices than low-end adopters, and that these BEVs will be of the same make as their current vehicle. Is it also possible that because of these more positive results they have been willing to spend a higher premium on their BEV compared to low-end adopters?

Prior to this investigation it was expected that both sets of adopters would have paid premiums in the region of US\$5,000-16,650 as the literature suggests (Hidrué et al., 2011; Kurani et al., 1996; Potoglou and Kanaroglou, 2007). Therefore it was expected that the US\$23,845-42,400 that low-end adopters had spent on a BEV would have been US\$5,000-16,650 more than an ICEV that they had previously purchased. It was also expected that owners of the US\$70,000-105,000 Tesla Model S would have spent US\$5,000-16,650 more on their BEV than they did on an ICEV. Meaning that on the whole BEV adopters would have purchased a BEV in replacement of an ICEV in a similar vehicle class. The BEV costing more than that similar vehicle due to higher costs associated with the new technology.

### **9.2.1 Difference in Purchase Price Paid**

Figure 9.1 shows what premium early adopters have been actually paid for their current BEV. The figure shows data indicating the difference in purchase price between adopters current BEV and an ICEV they would usually have purchased. The

histogram shows two distinct clusters, these are between US\$0 and US\$20,000 and a second between US\$30,000 and US\$60,000. This was unexpected and shows that some early adopters have been willing to pay a significant premium for their BEV over an ICEV. These two clusters could be due to the two distinct groups of adopters. Therefore frequencies were tested for both high and low-end adopters, these are presented below. There are a number of respondents whose difference in price paid is negative, in total 50 respondents returned a negative figure, meaning that the BEV they have adopted cost less than the ICEV they would have usually purchased.

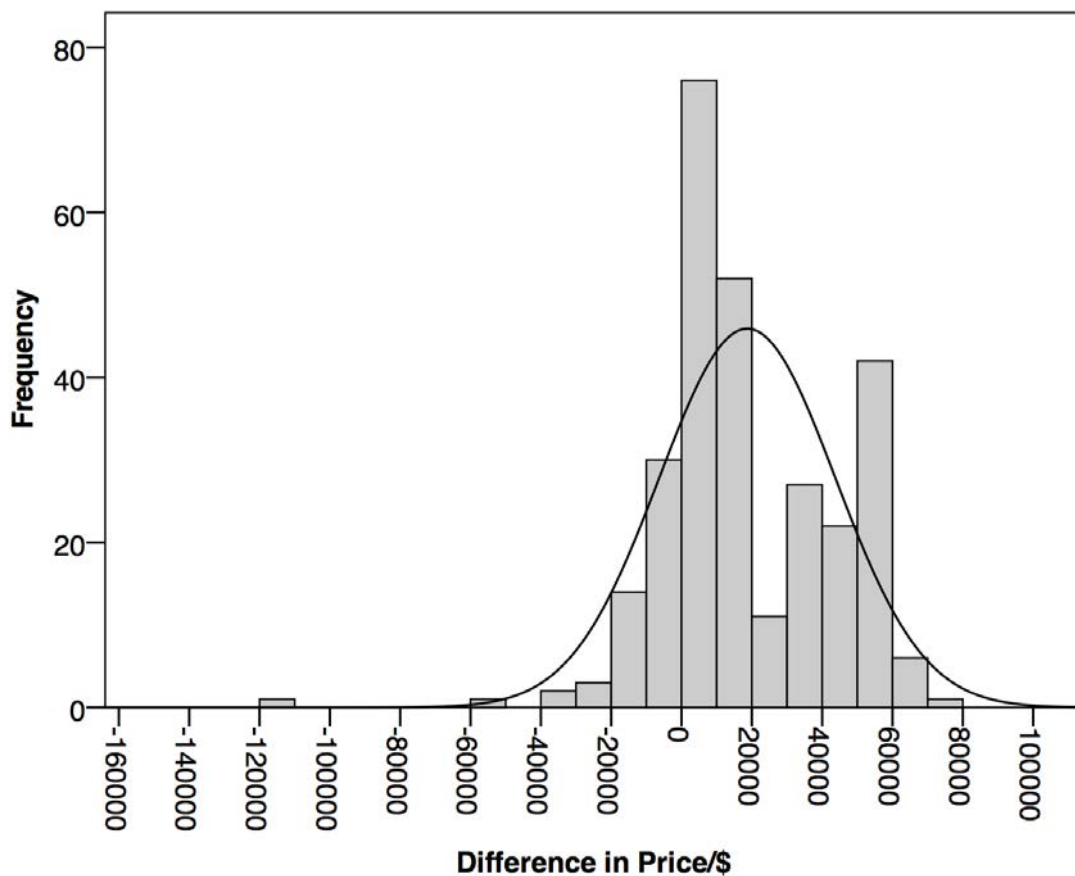


Figure 9.1: Histogram showing the premium paid for a BEV for all early adopters, in comparison with an ICEV they would usually have purchased (n=288).

Figure 9.2 shows the difference in purchase price paid for a BEV for low-end adopters. This data shows that the majority of these adopters are willing to pay between US\$0 and US\$15,000 more for a BEV over an ICEV. This data supports the findings of (Hidrue et al., 2011; Kurani et al., 1996; Potoglou and Kanaroglou, 2007). There is some interesting outlying data, with one adopter spending US\$55,000 less and another US\$35,000 less on a BEV compared to their previous ICEV. These were previous owners of a US\$84,300 Porsche 911 and a US\$64,200 BMW M3. Both of these adopters purchased a Nissan Leaf, which was far cheaper than their previous vehicles. For this sample the mean value was US\$3,932 and the median value US\$5,350. The number of low-end respondents with a negative figure was 40. Further investigation of the data reveals that these 40 people have not only transitioned from an ICEV to a BEV, but they have also changed vehicle types. The previous vehicles of these individuals include 12 SUV's and pick-up trucks, 17 premium saloons, 3 sports cars, and also mini vans. These drivers have therefore gone through a significant change by not only transitioning from an ICEV to a BEV but also changing vehicle types. They have gone from large luxury vehicles to a more compact hatchback style vehicle that is a BEV rather than an ICEV. And this change in vehicle type is partly responsible for the negative figure, the vehicle types they previously owned usually cost more than a hatch back style vehicle, of which most low-end BEVs are.

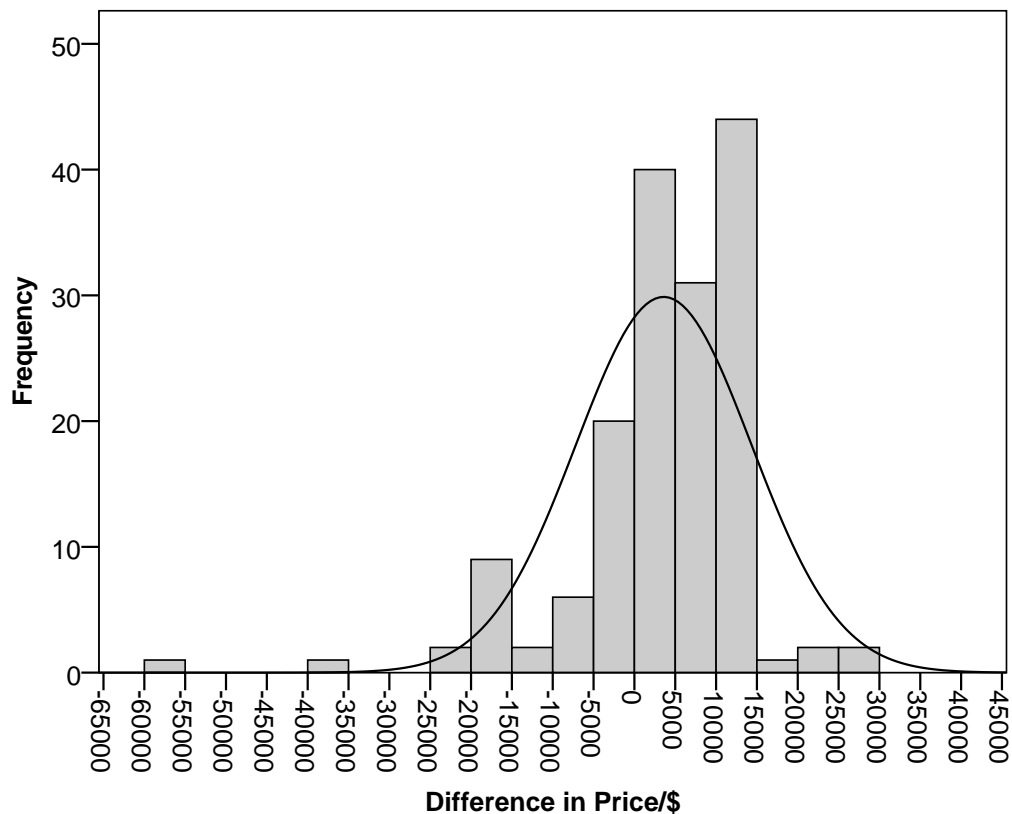


Figure 9.2: Histogram showing the premium paid for a BEV for low-end early adopters (n=162).

Figure 9.3 shows the same data for the high-end adopters in this sample. This shows that the majority of the sample has paid a premium of US\$30,000-US\$60,000. This is far higher than what was expected. Again this data has some anomalies with one previous owner of an Aston Martin DB9 spending US\$110,050 less on a BEV and the previous owner of a BMW 760i spending US\$39,100 less. Nevertheless, this data shows that high-end adopters are willing to spend a significant premium on a BEV compared to an ICEV. The mean for this data is a premium of US\$37,686 and the median US\$40,285. Far higher values than what has previously been reported. They are also far higher than what has been reported for low-end adopters and a T-Test

comparing the means reveals that this difference is statistically significant at  $<0.001$ . Furthermore, there are far fewer high-end respondents with a negative figure, 10 in total. These respondents' previous vehicles were premium luxury cars. These vehicles include 8 large luxury saloon cars. There was also an owner of the aforementioned Aston Martin DB9 and a large luxury SUV.

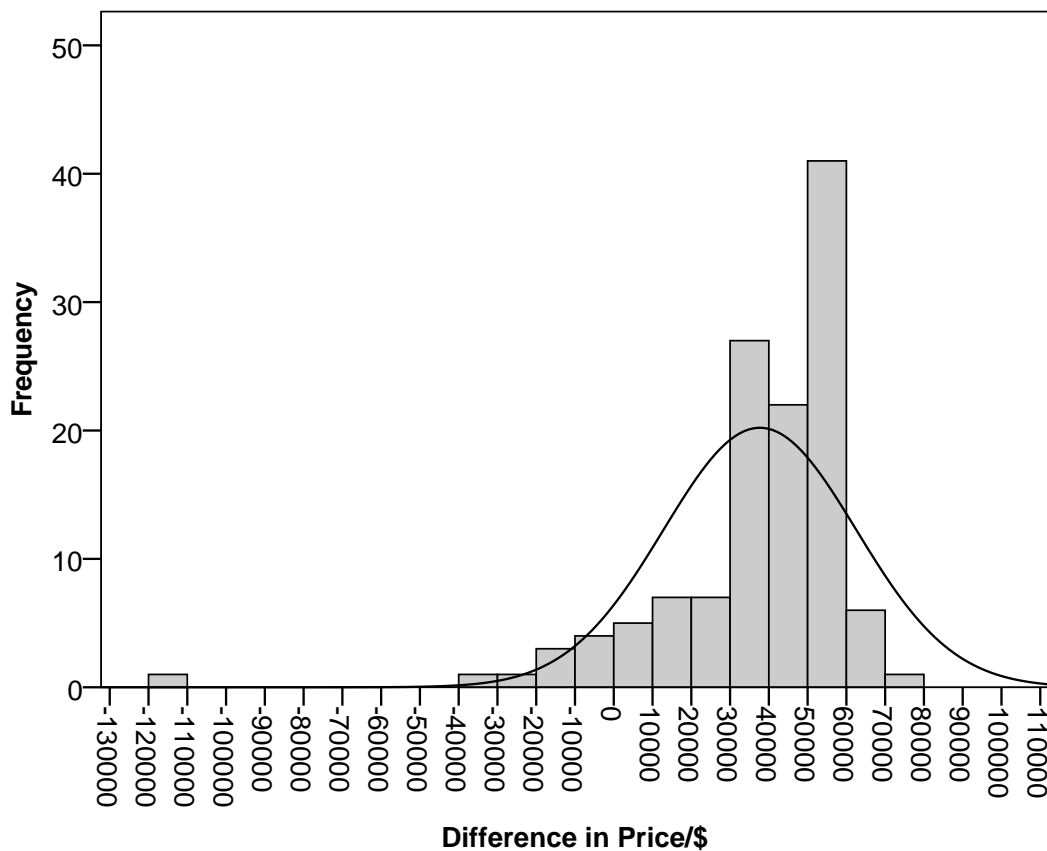


Figure 9.3: Histogram showing the premium paid for a BEV for high-end early adopters (n=126).

### 9.3 Conclusion

This chapter shows the price premiums paid for BEVs by consumers who have actually bought a BEV. Previous studies have presented 'willingness to pay' data all

based on attitudinal surveys or choice experiments, which ask respondents how much they would hypothetically pay for a BEV (Hidrue et al., 2011a; Kurani et al., 1996; Potoglou and Kanaroglou, 2007). The data in this chapter presents what people have actually been willing to pay for a BEV. There are two groups of early adopters in this study, high and low-end adopters. Low-end adopters are willing to pay an average of US\$3,932 more for a BEV. High-end adopters are willing to pay an average of US\$37,686 more for a BEV. This difference in price paid between each vehicle type is the major contribution of this chapter. For low-end adopters the price of a BEV is not much dissimilar to the price of an ICEV they would otherwise purchase. The difference in price for high-end adopters is far greater. This data is vastly different from what is reported in previous studies and therefore was totally unexpected. The data for low-end adopters was in line with values cited in literature, however, the results presented here for high-end adopters are not. This might either indicate that purchase motivations are underestimated in attitudinal surveys and that high-end adopters are not sufficiently covered by these surveys. It could also mean that these previous studies assume that consumers are rational in the way they make their decision, or they are motivated in their purchase decisions due to financial motivations. Furthermore it may suggest that low-end adopters value their BEV less due to them being considered as similar or worse than an ICEV in some areas, as the previous chapter showed. High-end adopters may value their vehicles higher due to them viewing their vehicles as being superior to ICEVs. They therefore are willing to spend a greater premium for the vehicles to access these perceived benefits.

It was hoped that multiple linear regression analysis could be used to compare the price premiums paid presented in this chapter, with opinions of vehicle attributes

presented in chapter 8. Using a stepwise method it was hoped that the attributes that have the most significant impact upon these price premiums would be revealed. These models were unsuccessful in doing this. When all independent variables were compared to the dependent the ANOVA for the model was indeed significant, which means that opinions of vehicle attributes do influence the premium paid for a BEV. However, it was not possible to state which independent variables are significant contributors, due the absence of any statistically significant sig. values.

### **9.3.1 Managerial Implications**

The results presented in this chapter are positive for AFVs as they suggest that cost is not a significant barrier to market entry. The results are more positive than previous studies have suggested because the level of premium a certain segment of the population are willing to pay for their desired BEV is far higher than what previous studies have found. An additional positive for automotive OEMs is that almost all respondents in this chapter purchased a BEV of a different brand from their previous vehicle. Automotive OEMs may be able to leverage BEVs to attract customers that would not have usually bought a vehicle from their company, therefore potentially allowing them to gain market share from competitors. OEMs may also be able to increase sales revenues by attracting consumers to BEVs that are more expensive than ICEVs they would usually purchase, and if BEVs can be made profitable net incomes will increase. Finally, automotive OEMs need to decide on the optimal market entry strategy for their BEVs. The product decision, in terms of which attributes to build into a BEV and which attributes to promote, may be more important than the pricing decision alone. If the product development is well guided leading to

the benefits of the vehicle being easy to communicate to consumers a larger proportion of the population may be willing to pay a larger premium for BEVs.

### **9.3.2 Policy Implications**

Currently BEVs receive grant support for transportation policy reasons in a number of countries. In the USA up to US\$7,500 of federal tax credits are available, with additional rebates available in some states, for example US\$2,500 in California. Based on data reported in this chapter, these grants will be important for low-end adopters whose price premiums paid are on average US\$3,932. This means that for many low-end adopters the grants mentioned are enough to level the purchase price of a BEV to the same as or a lower value than an ICEV. Further to this, low-end adopters are of lower socio-economic status than high-end adopters and have been shown to be motivated to adopt due to financial considerations (Caperello et al., 2015) so these grants will be important to them. High-end adopters spend on average US\$37,868 more on a BEV than an ICEV. With the grants available in USA this figure would still be significantly more than their previous vehicle. These adopters have exceptionally high incomes with 17.4% earning US\$400,000+ and 45.2% US\$180,001-400,000. Based on these facts, it might well be that the market entry of high-end BEVs is not totally reliant upon purchase incentive support from transportation policies. In order to understand this further the importance of these grants to high-end BEV adopters is explored in Chapter 10 of this thesis.

### **9.3.3 Academic Implications**

Pre-existing studies that look to assess consumer's willingness to pay for a BEV have all been based on predictive behaviour rather than actual behaviour (Hidru et



al., 2011; Kurani et al., 1996; Potoglou and Kanaroglou, 2007). Further to this they normally only consider one type of BEV, rather than the two different types considered in this chapter. This has resulted in an under prediction of consumers' willingness to pay for a BEV for high-end adopters. In order to address this, future studies should do two things; firstly data should be collected from actual adopters, and secondly studies need to consider that there is more than one type of BEV. By gathering data from early adopters the data will be representative of an actual decision process, thus avoiding any predictive errors. By considering both high-end and low-end BEVs the data will gain further accuracy. Consumers perceive high-end and low-end BEVs differently and they are willing to pay significantly different premiums for each vehicle.

#### **9.3.4 Limitations**

The results in this study are taken from actual behavioural data and not hypothetical data meaning they are more accurate and reliable than previous studies on this subject. However, the results do not take into account the incentives that are available off the purchase price of a BEV in some regions. This could mean that the results are less reliable in reporting the purchase price paid for a BEV. The statistically significant differences in purchase prices are the key theme of this chapter. Nevertheless, the accuracy of the data reported could be improved in future studies by taking into account the purchase incentives. Another limitation of this study is that it assumes that in the event a BEV adopter did not go ahead with the purchase of their electric vehicle they would have continued to own an ICEV as the same make and model as their previous ICEV. This along with the first limitation

could mean that the data is not truly representative of the actual price premium paid for a BEV.

In order to alleviate these concerns the data in this chapter was again compared to the UC Davis survey. That survey gathered data on the highest price paid for an ICEV in the household prior to BEV ownership. It also gathered information on the price paid for a BEV by the household including taxes, options, dealer costs and importantly the purchase incentive. Although this is a slightly different method of calculating the premium paid for a BEV the results still measure the same phenomenon. When informally comparing the data it was clear that a similar trend existed in both data sets. The UC Davis data suggested a large difference in the price premium paid for a BEV for consumers who adopted a low-end BEV and a high-end BEV. The people who adopted a high-end BEV were found to have spent a large premium for their BEV compared to any ICEV that they had purchased previously. The low-end sample were found to pay a similar price for a BEV as they had previously spent on ICEVs. Although no statistical analysis was possible this still gives greater confidence to the findings in this chapter, and the author of this thesis is in talks with UC Davis to produce a publication that uses both sets of data in order to explore the willingness to pay for a BEV.

# CHAPTER 10

An in-depth qualitative investigation into  
high-end battery electric vehicle adopters

# Chapter 10 An in-depth qualitative investigation into high-end battery electric vehicle adopters<sup>5</sup>

## 10.1 Introduction

Based on the results presented in chapters 8 and 9 the adopters of Tesla BEVs, or high-end adopters, are an interesting case. Firstly they are more representative of early adopters due to their psychographic and socio-economic profile when compared to low-end adopters. They have far better perceptions of their vehicles than low-end adopters do, and this leads to a higher intention to continue with BEV ownership, and low amounts of discontinuance. They have also been found to spend a significant premium on their BEV compared to their previous ICEV. Therefore, a more in-depth investigation into the adopters of Tesla BEVs and what motivates their decision to adopt an AFV is needed, and this can be gained through gathering in-depth qualitative information. This chapter presents data gathered from 39 in-depth interviews with early adopters of high-end BEVs. The results from these interviews were analysed in NVivo using the approach of grounded theory analysis, which is discussed in detail in the methods chapter and explained in (Bryman and Bell, 2015). This makes the results more reliable and credible by avoiding the risk of any confirmation or expectancy bias occurring.

This chapter explores a number of topics, each time concentrating only on high-end adopters. First their socio-economic profiles are explored, and as the results will

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<sup>5</sup> Some of the results in this chapter are taken from part of the publication Hardman, S. & Tal, G., 2016. **Exploring the decision to adopt a high-end battery electric vehicle: The role of financial and non-financial motivations** *Transportation Research Record Journal of the Transportation Research Board*, 16-1783

show it is found that they are comparable to the high-end adopters in the questionnaire survey. Second the purchase motivations of these adopters are explored; this has not previously been covered in this thesis or in the literature. The results will provide some unexpected trends. Then this chapter explores what impact financial purchase incentives have on the decision to adopt a high-end BEV. Next the benefits of owning a high-end BEV are explored. The results here support the findings from chapter 8, but also bring new information to light. This is due to the method of in depth interviews, which allows themes that the questionnaire might have overlooked to be picked up. Finally the results in this chapter explore the future purchase intentions of this sample. The results will show that because of the significant benefits of owning a high-end BEV the future purchase intentions are extremely positive.

## **10.2 Results**

The results in this chapter come from the first part of the in-depth interviews with the 39 high-end BEV adopters. This part of the interviews solely explored BEVs, with interviewees' socio-economic profile, reasons for purchase, benefits of ownership and other topics being explored in detail.

## **10.3 Socio-Economic Profile**

Most interviewees are director or executive level within their respective companies, or are retired now and were previously in these positions. The ones not in these positions are university professors or medical doctors. Of the 39 interviewed, 19 work in the software or computing industries, mostly in the Silicon Valley area. 4 work in jobs related to the environment, 3 are professors at universities, 4 work in the

medical sector, 2 work in the electric vehicle industry and 2 work in engineering. 5 high-end BEV owners do not have careers with any tangible link to the environment, technology or electric vehicles. Level of education is high with 18/39 having completed an undergraduate degree, 11 a masters degree and 7 have a doctorate or medical degree. Therefore only 3 had not obtained a university level degree, with 1 of these starting an undergraduate degree but not completing it. 33 males were interviewed in this study, and only 6 females. This is a low representation of females, but is still higher than previous studies (Hardman et al., 2016). Age of interviewees is spread widely; the youngest interviewee was 35 and the oldest 80. Most interviewees were middle aged, though, with 8 aged 40-49, 10 aged 50-59 and 11 60-69.

Car ownership is high at 2.5 cars per household, which is in alignment with the quantitative questionnaire survey data. What is interesting in this sample is that 11 households have 2 BEVs and 1 household has 3 BEVs. 11 households do not own any ICEVs, these households have fully transitioned to BEV ownership. A further 5 households don't own any conventional ICEVs, but have HEVs in addition to their BEVs. Meaning 16 households are all AFV households. There are 52 electric vehicles in this study, 41 of these are Tesla BEVs meaning two households have 2 Tesla's. The most common Tesla BEV in the study is the Model S 85, of which there are 18. The non-Tesla BEVs that adopters also own include 4 Nissan Leafs, 5 Toyota Rav4 BEVs, 1 Smart Electric Drive and 1 THiNK City. Table 10.1 shows the socio-economic profile of the individual interviewees.

Table 10.1: Gender, number of household cars, number of household BEVs, primary vehicle, level of education, age and profession of all 39 interviewees.

Interviewee Number	Gender	Number of Household Cars	Number of Household BEVs	Primary Vehicle	Highest Level of Formal Education	Age	Profession
1	Male	3	1	Model S P85	Bachelors	65	Electric Auto Industry
2	Male	2	1	Model S 60	Masters	35	Electric Auto Industry
3	Male	2	1	Model S 85	Masters	45	Software or Computing
4	Female	5	2	Model S 85	Masters	45	Law
5	Male	1	1	Model S 85	Bachelors	70	Engineering
6	Male	2	2	Model S P85	Bachelors	50	Coffee Shop Owner
7	Male	1	1	Model S P85D	Doctorate or Equivalent	70	Professor
8	Male	2	2	Model S 85	Doctorate or Equivalent	65	Professor
9	Female	3	1	Model S 60	Masters	50	Environmental
10	Male	3	1	Model S P85	Doctorate or Equivalent	50	Professor
11	Male	1	1	Model S 85	Masters	70	Medicine
12	Male	2	1	Model S P85	Doctorate or Equivalent	50	Medicine
13	Male	2	1	Model S P85	Masters	65	Environmental
14	Male	4	1	Model S 85	Masters	60	Software or Computing
15	Female	3	1	Model S 85	Bachelors	45	Business Consultancy
16	Male	3	2	Model S P85	Bachelors	50	Software or Computing
17	Male	3	1	Model S P85	Doctorate or Equivalent	45	Medicine
18	Male	2	1	Model S P85	Bachelors	65	Bio-technology
19	Female	2	2	Model S 85	Bachelors	60	Environmental
20	Male	4	1	Tesla Roadster	Masters	55	Environmental
21	Male	3	2	Tesla Roadster	Some Undergraduate	65	Software or Computing
25	Male	3	2	Tesla Roadster	Masters	65	Software or Computing
26	Male	3	3	Model S 85	Masters	75	Engineering
22	Male	2	1	Model S P85	Bachelors	50	Software or Computing
23	Male	3	2	Model S P85	Bachelors	35	Software or Computing
24	Male	2	2	Model S 85	Bachelors	80	Software or Computing
27	Male	3	2	Model S 85	High School	60	Software or Computing
28	Male	1	1	Model S 85	Bachelors	35	Software or Computing
29	Male	2	1	Model S 85	Doctorate or Equivalent	60	Software or Computing
30	Male	2	1	Model S 85	Bachelors	75	Software or Computing
31	Male	2	2	Model S P85	Doctorate or Equivalent	65	Venture Capitalist
32	Male	3	1	Model S P85	Bachelors	40	Software or Computing
33	Male	2	1	Model S 85	Bachelors	50	Software or Computing
34	Female	3	1	Model S P85	Masters	40	Medicine
35	Male	1	1	Model S P85	Bachelors	55	Software or Computing
36	Male	2	1	Model S P85D	Bachelors	40	Software or Computing
37	Male	4	1	Model S 85	Bachelors	40	Software or Computing
38	Male	3	1	Model S 85	Bachelors	50	Software or Computing
39	Female	2	1	Model S 85	High School	35	Software or Computing

## 10.4 Purchase Motivations

From the interviews it emerged that adopters of high-end BEVs are characterised by an enthusiasm for performance vehicles, new technologies or the environment. There is some overlap between performance, technology and environmental motivations for purchase, with some interviewees being enthusiastic about all three. Interviewee 7 uses his Model S for drag racing, has a smart watch and smart phone but is also interested in the environment, has solar panels and had previously owned a Nissan Leaf and Chevy Volt. Their motivation is threefold, however most interviewees have an affinity to just one or two of these areas. A further result of this study is that these consumers are not cost conscious consumers, this is contrary to existing findings (Caperello et al., 2015). For these interviewees performance and technological or environmental motivations are far more important than cost savings.

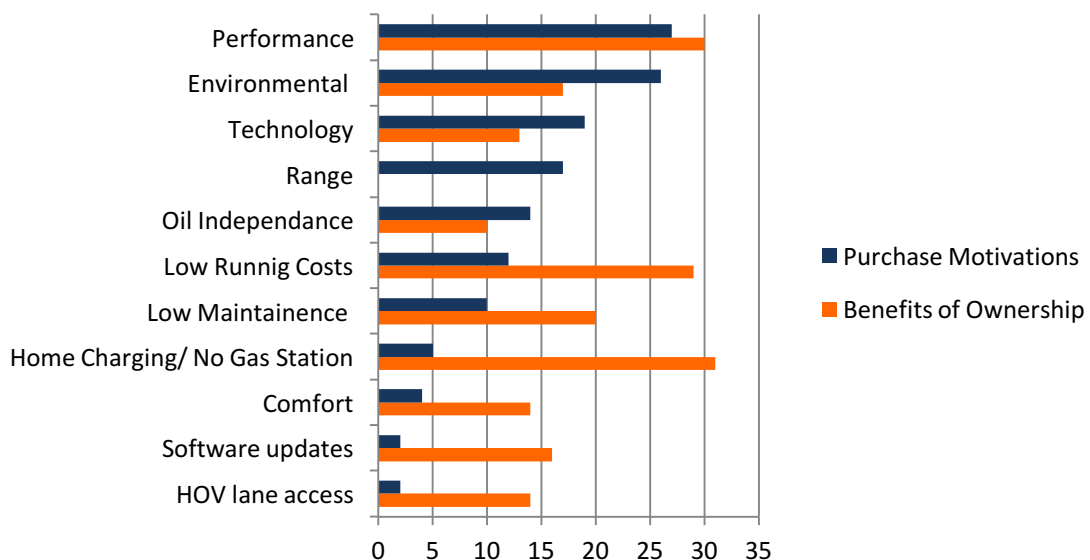


Figure 10.1: Purchase motivations and benefits of ownership and high-end battery electric vehicles (n=39).



### 10.4.1 High Performance Adopters

The most prominent reason for adoption of a Tesla is due to the vehicle's high performance, mainly the acceleration. This was mentioned by 69.2% (27/39) of interviewees as being a reason for purchasing the vehicle. Adopters mentioned this frequently and with much enthusiasm;

*"It was fast, and it was fun to drive."*  
Interviewee 7

*"It was good performance which again fit with the [Dodge] Viper"*  
Interviewee 18

*"I mean the Tesla has many of those performance visceral rewards, with none of the bruises of upkeep and maintenance"*  
Interviewee 7

These adopters' previous vehicles, which they replaced with their Tesla include: a Ferrari 360, a Dodge Viper GTS, a Chevrolet Corvette, a Lotus Exige, a BMW M3 and a BMW 550i amongst others. These performance-oriented consumers are enthused about the acceleration, speed and road handling of their vehicle.

### 10.4.2 Technological Adopters

Some adopters are motivated in their purchase decision for technological reasons. Of particular note is the household with three BEVs. The interviewee is eager to note that he is a climate change sceptic. His reason for adoption was because he liked the technology of the vehicles. There are more interviewees whose reason for adoption is technology-related. Many of these interviewees work in Silicon Valley for software or computing companies. The high-technology nature of the vehicle was mentioned by 48.7% (19/39) of interviewees.

*"I'm a geek at heart, so I just appreciate the technology of this."*  
Interviewee 3

*"I'm a early adopter of all new technologies, I stayed up last night and hit buy on a  
Apple Watch at 12:01am."*

Interviewee 12

(On the day of the release of the new Apple Watch)

### **10.4.3 Environmental Adopters**

There are adopters whose motivations are related to environmental concerns. In total 58.9% (23/39) interviewees cited these reasons during the interviews. After being asked about the reasons for purchase of a BEV, interviewee 29's first statement was; *"I have long been concerned with the issue of the environment and global warming"*. This person had strong environmental preferences. 7 adopters however had to be given a cue in order to get them to talk about this subject. When asked further questions about the environment these 7 interviewee's answers are without complexity or depth, suggesting that it is not a primary motivator. 16 mentioned environmental reasons without a cue, these people exhibited strong motivation toward environmental protection along with a good understanding of the issue. This therefore suggests that 41% (16/39) have environmental motivations. Another 16/39 interviewees indicated that they didn't have any environmental motivations. Most stated that it was something that they had not given much thought to, or that they were not interested in the environment, these adopters' motivations were related to performance or technology.

### **10.4.4 Non-cost Conscious Adopters**

Often financial savings, due the low running costs, are cited as a motivation for purchase of a BEV (Caperello et al., 2015; Hidrue et al., 2011). This was not

observed in this study. An emergent theme was that cost savings do not motivate these adopters. Only 12/39 (30.7%) interviewees believed that low running costs were a reason for purchasing a high-end BEV. The remainder of respondents did not see this as an incentive. There are three reasons for this. Firstly, many indicated that their incomes are so high that it was not of consequence.

*“No, I’ve said that, but I don’t believe it.” The interviewee then went to on say “The cost of the car is not important to me.”*

Interviewee 1

Secondly, adopters stated that the Tesla BEVs cost significantly more than their previous vehicle meaning they would not see a financial pay back.

*“The cost of the car is so much that using that [low running costs] as an argument is very difficult, even in the long run”*

Interviewee 17

Finally some respondents are willing to make a financial sacrifice in order to live a sustainable life style. These respondents showed a willingness to pay a premium for products that are environmentally superior, and one respondent indicated that they would own a BEV even if they had higher running costs than an ICEV.

*“I can’t imagine anybody who has had the same life time commitment to the environment and to energy efficiency, and a willingness to pony up the money to do the efficiency thing, there is just nobody like us in that regard.”*

Interviewee 18

## **10.5 The Impact of Purchase Incentives**

All 39 interviewees indicated that they did take advantage of the purchase incentives that are available in California. The US\$2,500 California clean vehicle rebate was beneficial to all respondents equally. The US\$7,500 federal tax credit resulted in different financial savings between respondents. As was discussed in (Hardman and

Tal, 2016) the majority of Tesla adopters received the full US\$10,000 that is available. This was due to high incomes, which mean that Tesla adopters had a high-enough tax liability to be able to get the full tax credit. Interviewees were asked, 'If the state and federal incentives were not available would you have purchased your Tesla?' Of the 37 who were asked 27 respondents indicated that they would have still purchased a Tesla BEV without the incentives, 3 respondents indicated that they would not have purchased the Tesla, 5 maybe would have not and 2 said that they maybe would have, this is shown in the left hand pie chart in Figure 10.2.

The 3 interviewees who would not have purchased a Tesla without the incentives, indicated that they are not as wealthy compared to most Tesla owners. Of these 2 would not have purchased an electric car at all without the incentive. The third might have, and had previously owned electric vehicles, including 2 General Motors EV-1s. The first of these two persons indicated previously in the interview *"We took into account the upfront cost of the vehicle, the available tax credits and purchase incentives [before buying the vehicle]"*, therefore the incentives were important to them. 27 interviewees indicated that they would have purchased their Tesla without any purchase incentives. Many are quick to state that they definitely would have purchased the vehicle, interviewees stated;

*"Absolutely would have yes."*  
Interviewee 11

*"Sure that wasn't that important."*  
Interviewee 25

*"Did it make any difference on whether I would buy the car or not? Not an iota."*  
Interviewee 6

17 interviewees answered in an abrupt and certain manner, they were able to immediately state that their purchase decision would not have changed if either incentives were not available. The remaining 10 interviewees who stated that they would have purchased their Tesla without the incentives took more time to consider their answer. The reasons for their uncertainty was due to a number of reasons, firstly due to a concern that if they are vocal in admitting the purchase incentives are unimportant they might penalise future adopters, for example interviewee 10 remarked, after being asked the question for a second time;

*“Yea probably, I guess I’m ruining it for everyone else when I say this because then they will take away the subsidies”*

Interviewee 10

Another reason for hesitation was due to the incentive allowing the purchase of more options, or a more expensive version. In these cases respondents believed that without the incentive they may have chosen a less expensive Tesla. One interviewee was unable to decide if their hypothetical decision, in hindsight, would be different than their actual decision when purchasing the car. They believed that now they have experience with the vehicle and understand all of the benefits they would have still purchased the vehicle. This respondent and another indicated that they have ordered or are going to order the Tesla Model X. Both stated that they will still purchase this next vehicle even if the incentives are not available.

### **10.5.1 Exploring the Insignificance of the Incentives**

In order to understand why the financial incentives are not influential in the decision for so many, the interviewees were asked to explain the reasons behind this. A breakdown of the reasons can be seen in Figure 10.2. The underlying reason for the

incentive being of insignificance is most likely related to respondent's exceptionally high incomes, shown in Chapter 8 and the publication (Hardman and Tal, 2016). Furthermore these BEV adopters did not purchase their vehicle to save money, it often did not weight into the decision to adopt. For example, when asked about running costs, one interviewee stated that he had no idea about the cost savings of the vehicle, they then located a calculator, worked out how much they are saving per year and were pleasantly surprised by their calculations, but they had not previously considered this.

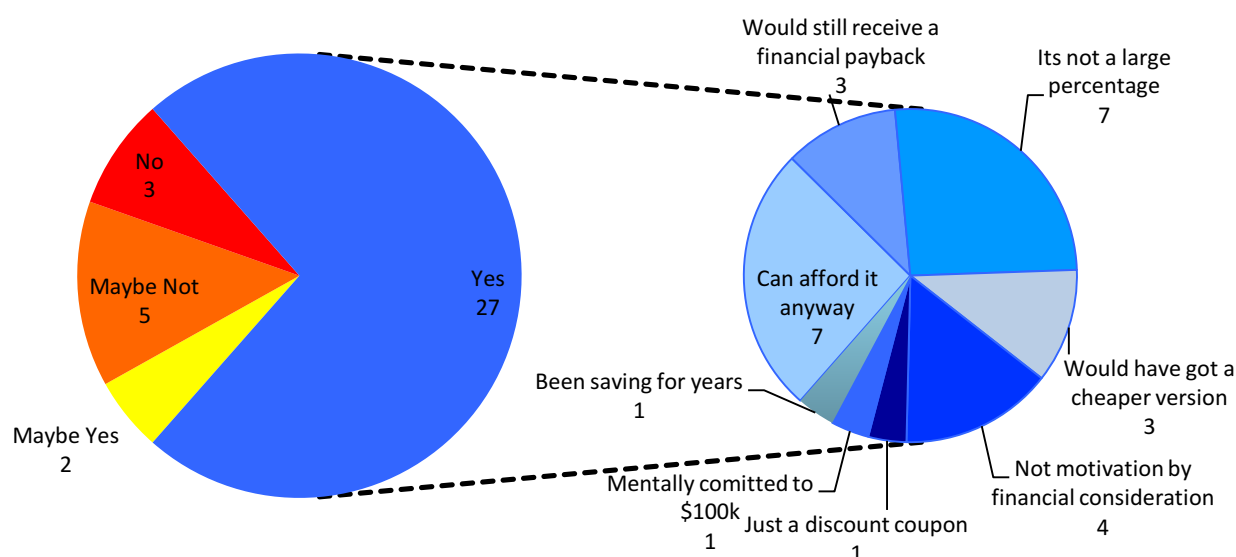


Figure 10.2: Answers to the question 'If the state and federal incentives were not available would you have purchased your Tesla?' on the left pie chart and breakdown of the reasons respondents indicated that the purchase incentives are not important in their decision to adopt a high-end BEV on the right hand pie chart (n=37).

When talking about their reasons for purchase 7 respondents indicated that they have enough money or income to afford the vehicle regardless of the incentive. All of

these people had more prevalent reasons for purchase, 3 had technological motivations with 2 being performance motivated and the other 2 having global environmental concerns.

*"I don't live beyond my means so, luckily having busted my butt when I did, I can afford it."*

Interviewee 10

*"Its probably just because I could afford it."*

Interviewee 18

3 owners did justify their answer by making reference to the low running costs. Two of these interviewees made comparisons between the Tesla Model S and vehicles they would have purchased if they did not purchase a BEV, these vehicles are a BMW 7 Series and a Mercedes-Benz E320. The respondents indicated that these would have cost US\$90,000 and US\$67,000 respectively. They calculated that they would have still been able to make a financial case for their BEV if the incentives were not available, and one of them stated that they will purchase a Model X even if the incentives are not available. The third did not make a connection to the vehicle they would have purchased. They stated that because of their previous experiences in an electric vehicle ownership trial they are aware of the running costs savings. Their previous ICEV, a BMW M3, would have cost US\$64,200, suggesting that a financial payback could be possible.

*"To me it would have meant that it would have taken another two years to basically pay the difference between a 7 Series and a Tesla."*

Interviewee 31

7 respondents indicated that they believed the incentive was not a large amount of money when you consider the purchase price of the vehicle, which for most responds was close to or more than US\$100,000. These interviewees believed that the

US\$2,500 California state incentive and the US\$7,500 federal incentive are not a large amount of money compared to the total price of the vehicle. Interviewee 26, the owner of a Model S 85, a Nissan Leaf and a TH!NK City indicated that in the absence of the incentives they would not have purchased the Leaf or the City, but would have still purchased the Tesla.

*"Its really a small percentage when you get into these higher number cars."*

Interviewee 11

*"At that price range the \$10,000 was a small percentage of the effect."*

Interviewee 26

For 3 respondents the incentive assisted them in purchasing a different model of the vehicle. The car is or was available in 40, 60, 70D, 85, 85D, 90D, P85, P85D & P90D versions, with respondents in this study having 60, 85, P85 and P85D vehicles as is shown in Table 10.1. Each of these models costs more than the last. These respondents indicated that in absence of the incentive they would have still purchased a Tesla BEV but it may have been a less expensive version.

*"I might have given the 60 a longer look at that point, instead of the 85."*

Interviewee 27

*"Whatever I saved by that I blew by buying the P [P85] version."*

Interviewee 12

4 respondents are driven by personal values or a desire to make a difference. They did not purchase a BEV to achieve running cost savings. Interviewee 23 for example, indicated that they are not doing this for the money, this person had strong environmental motivations for their purchase, and they had also installed solar panels on their home. Another one of these interviewees was motivated to access the high



technology of the vehicle, earlier in the interview they professed, *“I’m a Geek at Heart”* and they currently worked for a software company.

*“Because I’m not doing it for the money.”*

Interviewee 23

*“Its not necessarily a financial decision.”*

Interviewee 3

One respondent compared the incentive to a discount coupon *“Its like having a coupon for getting something that’s just a tiny bit off, you feel like your getting something back”*. They believed that the incentive wasn’t important and that it was just a pleasant feeling by getting some money back. This person was already in the high-end of the automotive market having owned a Dodge Viper GTS previously, which would cost US\$110,000 in 2015. Another respondent stated, *“I had already mentally committed to \$100k”*. Meaning that they wanted to purchase the vehicle at that price prior to being aware of the US\$10,000 of incentives. They were more motivated for technological reasons. One final reason was because the interviewee had been saving for a vehicle like the Tesla Model S for 10-15 years. They had previously been interested in BEVs in the late 1990s and had driven a number of vehicles back then, but they were able to secure one for purchase and did want to lease a vehicle. Since then they had been waiting for a practical BEV with good range and did consider a Tesla Roadster but believed it was too small and impractical.

*“We had been saving and dreaming of a car like this for 10 or 15 years and it was our goal, I mean for 20 plus years he was not replacing his car because there wasn’t what we wanted available on the market until the Model S came into existence.”*

Interviewee 13

### **10.5.2 Summary of Incentive Impact**

The financial purchase incentives available in the United States have no influence on 75% of high-end adopters purchase decisions with interviewees stating that they would have purchased a Tesla BEV without these. This figure is close to the number reported by (Tal and Nicholas, 2016), who find that 86.1% of a sample of more than 540 adopters would have still purchased a Tesla without the US\$7,500 tax credit. From the interviews it emerged that the incentive is not important due to the following reasons: high incomes mean adopters are able to afford a high-end car regardless of the financial incentives, the decision to buy the vehicle is not financial, the vehicle would deliver a financial pay-back even without the incentive, the incentive was not a significant percentage of the vehicles purchase price, the incentive just allowed the purchase of a more expensive version of the vehicle or because the interviewee had been saving for this vehicle for many years. The incentives were part of the purchase decision for 25% of these adopters, though, which is not an insignificant number.

### **10.6 Benefits of Ownership**

Again three trends emerged as the most significant benefits of owning a high end BEV, however only one of these benefits was the same as one of the reasons for adoption, this was performance. The remaining benefits of owning a high-end BEV are due to their low running costs and the ability to recharge at home. Again there is some overlap in these areas with some consumers stating all three as a benefit; most respondents stated two of these areas as a benefit. Home charging has not previously emerged as a significant benefit so it is discussed in detail here, after the more obvious benefits of performance and running costs have been addressed.

### **10.6.1 Performance**

With performance being the leading reason for purchasing a high-end BEV it is not surprising that this is also a significant benefit of owning the vehicle; 30/39 (76.9%) interviewees mention this. When talking about the performance of the vehicle, interviewees state that the acceleration and good handling make their vehicle fun to drive.

*“The driving of it is so much fun.”*

Interviewee 19

*“I love the way it drives, it is fun to drive.”*

Interviewee 31

### **10.6.2 Running Costs**

Despite only 12 interviewees stating that low running costs are a reason for purchase, 29/39 (74.35%) state this as a benefit of owning the vehicle. Interviewees mostly spoke about the benefit of low refuelling or recharging costs. Some interviewees had accurate knowledge of their recharging costs as they monitored their smart electricity meters, which broke down their electricity bill into categories so they could see the cost to recharge their BEV. Low maintenance costs also contribute to the low running costs. Interviewees state that the service costs were much cheaper compared to what they had experienced with ICEVs. The maintenance costs of BEVs are lower than ICEVs mainly due to the drive train having far fewer moving parts.

*“There is no moving parts; you’ve got to replace tires that’s about it.”*

Interviewee 19

This was not an emergent reason for the adoption of a high-end BEV. There were a number of reasons for this being a benefit, but not a motivational factor. Firstly respondents recognised that the car was more expensive than any previous vehicles they had and that a return on this investment was unlikely. And secondly this was because the early adopters are not motivated in their adoption decision. The low running costs are nevertheless a financial benefit of owning BEVs. This supports the finding from chapter 8 that revealed low running costs were a compelling benefit that lead to increased likelihood of purchasing a BEV in the future.

### **10.6.3 Battery Electric Vehicle Charging**

In this study the way in which a BEV is recharged emerged as the most prominent benefit of owning a BEV. This is contrary to much of the existing literature, and therefore warrants further investigation in order to understand why these adopters perceive this is a benefit. 31 interviewees mentioned home refuelling as a significant benefit, 18 of these mentioned this without any cue from the interviewer. 13 had to be given a cue, after they alluded to the topic, in order for them to talk directly about this topic. Although these 13 interviewees had to be given a cue, home recharging still appeared to be a significant benefit for them. These interviewees spoke about additional benefits of owning a high-end BEV prior to talking about home recharging. This suggests that they are interested in features such as performance, low running costs and technology primarily, but nonetheless do see home charging as an important benefit.

Interviewees communicated this benefit in three different ways. They either stated that it was better to wake up with a full charge in the morning, better to not have to

visit a petrol refuelling station (sometimes referred to as 'gas station'), or simply that it was better to plug in at home. The most prominent ways in which interviewees mentioned that home charging was beneficial was because every morning when they woke up at the start of their day the vehicle would be full; 15 interviewees mentioned this. Also mentioned by 15 interviewees was that it was beneficial not having to stop for fuel when they were driving. Finally 5 respondents stated that it was a benefit to plug in at home. These situations are different to an ICEV, in an ICEV the amount of fuel in the tanks will obviously vary day to day depending on the amount of driving that has been done. Which means a certain amount of planning ahead is needed in order to ensure that people's days would remain on schedule and they would not be late for any commitments, or have to take detours from normal driving routes to refuel.

*"For me waking up with a full tank every morning is helpful. Sometimes I need to take my wife's Jeep [ICEV] and have to ask 'is it full?' And I would kind of have to work that into the day."*

Interviewee 3

*"Well I just plug it in every night and I get up in the morning and I have a full tank [full charge], its fabulous."*

Interviewee 12

*"You don't have to stop at the filling station, the fuel is cheaper, and you can fuel at home."*

Interviewee 2

There is a significant difference in the number of adopters who mention home charging as a benefit of ownership compared with the number that mention it as a reason for purchase. Only 5 interviewees mentioned home charging as a reason for purchasing their vehicle, compared to 31 mentioning it as a benefit of ownership. This suggests that it is a benefit that is only realised once people have experience of

the vehicles. This could be due to the idea that charging a BEV is negative, and only after adoption has occurred do adopters realise that this is not the case. One of the interviewees who mentioned this as a reason for purchase stated that they had always tried to visit refuelling stations as few times as possible, but this situation was not commonly observed in the interviews.

*“I said once to my wife that my goal in life was to go to a gas station the fewest number of times. And to me at that time it meant me running the car gas tank down to almost nothing. So I would go to the gas station fewer times in my life which was a pain.”*

Interviewee 5

8 interviewees do not believe that home charging is a benefit to them. 5 of these interviewees do not charge their vehicles from home. These respondents use a combination of work place charging or Tesla superchargers to refuel their vehicles. 3 of them had free work place charging, of these, 2 primarily use work charging whilst 1 uses both Tesla superchargers and work place chargers. The 2 remaining interviewees primarily used Tesla superchargers, which were located close to their homes. None of these respondents spoke about free public chargers. The remaining 3 interviewees charge from home but do not see this as a benefit. This was because they acknowledge that it takes far longer to recharge a BEV compared to an ICEV and because their vehicles have shorter ranges.

#### **10.6.4 Reasons Behind Charging Being Beneficial**

Interviewees gave 4 different reasons of why charging is a benefit of owning a BEV. These can be seen in Figure 10.3 each reason is explained in-depth below. The highest number of reasons mentioned by any one respondent was 4. Most respondents mentioned just 1 or 2 of the reasons. Recharging a BEV at home and

not having to refuel at a petrol station is beneficial because they find it more convenient, it saves them time, they find it easier and because they dislike petrol refuelling stations.

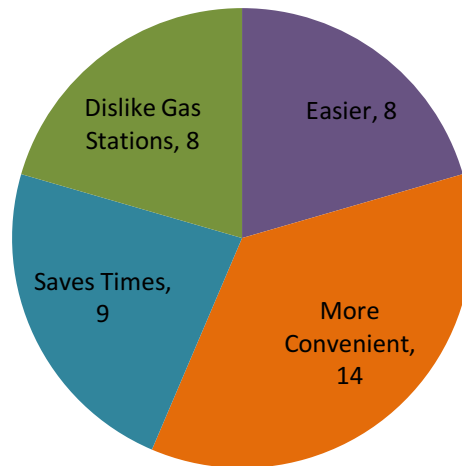


Figure 10.3: The 4 reasons for why home charging is viewed as a benefit of high-end BEV ownership (n=31).

### Convenience

14 interviewees believe that recharging their BEV at home is more convenient than ICEV refuelling. The ability of plugging in at home rather than visiting a centralised refuelling station is more favourable for them.

*“Absolutely yea, you do it at home, you don’t even think about it. Beside being good for the environment its actually more convenient.”*  
Interviewee 24

*“I like the convenience of never going to gas stations all the time.”*  
Interviewee 17

*“It’s incredibly convenient not to ever have to go to a gas station, or any other central place.”*  
Interviewee 7

## **Saves Time**

9 interviewees believe that refuelling at home is more time efficient compared to visiting a petrol refuelling station. This is surprising because BEVs clearly take far longer to refuel compared to an ICEV. An ICEV takes less than 5 minutes to fully refuel with petrol, the Tesla Model S takes a minimum of 75 minutes to recharge, and this is at a supercharger station. A home charge will take at least 4 hours to fully recharge. Despite this, interviewees perceive it as saving time. The reason is because drivers do not need to take any detour from a normal driving route to find a petrol station. The second reason is because the only interaction needed is plugging in the vehicle and then unplugging the next day, this takes a very short amount of time. Therefore less time is spent waiting by the vehicle compared to dispensing petrol from a pump and being captive until the vehicles tanks are full. Interviewee 3 states that it would take him 10 minutes to refuel an ICEV;

*“There’s gas stations on all four corners from where I live, but it’s still a pain in the butt. Its still at least 10 minutes of my time, rather than just unplug and go.”*

Interviewee 3

## **Easier**

In total 8 interviewees believed that it is easier to plug in a BEV. Some interviewees made a comparison between plugging-in a mobile phone and the ease of plugging in a BEV. The compatibility with these interviewees’ behaviour with a mobile phone means they are able to adapt to this new behaviour easily.

*“Its like my phone, the Tesla has timers so when I pull it into the garage I plug it in and at midnight/1 o’clock it will charge and its easy, there is nothing to it.”*

Interviewee 21



## Dislike of fuelling stations

8 interviewees believed that refuelling at home is better due to them disliking petrol stations. They stated negative aspects of petrol stations, which included the smell of petrol vapour, along with getting fuel on their hands. Interviewee 2 mentioned that they didn't like to get petrol on their hands and then pick up their children. With an electric vehicle charging cable no petrol or any other toxic substance gets onto their hands.

*"If you look at it in sort of absolute terms the process of putting a nasty chemical into your car, you know its smelly, your breathing fumes and everything its not pleasant."*

Interviewee 25

*"I don't have to smell the gasoline and so that's a plus, I don't have to sit there and get gasoline on my hands or whatever."*

Interviewee 10

*"The dirty handles that get greasy and icky."*

Interviewee 4

## 10.7 Future Purchase Intentions of Adopters

The benefits of owning a Tesla BEV are both functional and economic in nature. This leads to a high likelihood of repeat purchases of BEVs in this sample. Respondents were asked if they would go back to owning an ICEV with future vehicle purchases. The results of this question are shown in Figure 10.4. 31, of the 36 asked, indicated that they would not purchase another ICEV and intend to continue with BEV adoption. 1/36 would maybe not purchase an ICEV again but were not entirely sure that this was the case. 3 indicated that they would purchase an ICEV in the future. This was for a number of reasons; first one interviewee was approaching retirement and was considering an ICEV, which they would use on long road trips when they are

retired. A second respondent was considering an ICEV due to the low seating position of the Tesla Model S affecting their back; they were considering an ICEV SUV with a more upright seating position for their next vehicle. A final respondent was unsure of their future financial situation and were unsure as to whether they would be able to afford a BEV that costs “\$100,000” in a future vehicle purchase. They therefore may purchase an ICEV that was lower cost. All of these considering an ICEV in the future did not want to consider a different BEV to the Tesla, this was due to range limitations of the other BEVs. 6 interviewees indicated they would maybe purchase an ICEV; these interviewees may acquire a secondary vehicle that would be an ICEV, a further respondent indicated that they were interested in an ICE motorcycle. All 6 respondents were considering a sports car or convertible that they would drive only at the weekends for their leisure. The vehicle would not be their primary means of transportation.

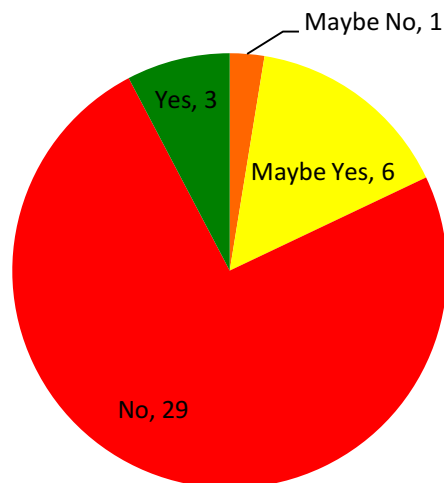


Figure 10.4: Answers to the question ‘Will you purchase an ICEV in a future vehicle purchase?’ (n=39)

## 10.8 Conclusion

The socio-economic status of the interviewees in this chapter is comparable to that of the high-end adopters in the questionnaire survey. Therefore high-end early adopters are highly educated, have a high number of household cars, and sometimes have more than 1 BEV. They are mostly male and have mostly technical professions, such as in the software industry.

The distinction between purchase motivations and benefits of ownership are important for this study, and indeed any BEV adoption study. Purchase motivations relate to attributes of the vehicles that lead to consumers making an innovation decision to adopt. Benefits of ownership do not lead to adoption, however they do contribute to repeat purchases and can prevent discontinuance from occurring. The results in this chapter show that the benefits of owning a BEV are not necessarily aligned with the motivations for purchase. One reason for this is because consumers do not anticipate some of the benefits before taking ownership, and therefore they only realise the benefits after purchase. An example of this is home charging of a BEV. Another reason is because BEVs have a large number of benefits which extend beyond individual consumers purchase motivations, nevertheless consumers do still enjoy these benefits during their ownership. One example of this is low running costs, which consumers are not motivated by, however it is clearly a benefit to them. Having a large number of benefits is important, and in this sample 29/39 of adopters intend to continue with BEV ownership in future vehicle purchases. The 3 who may not continue with BEV ownership were unsure of their next vehicle purchase.

Three reasons for the adoption of a high-end BEV emerged, these are environmental, high-performance and technological motivations. Low running costs are not a reason for adoption of a high-end BEV. The financial purchase incentives available in the United States do not influence 27/39 of high-end adopters purchase decisions with interviewees stating that they would have purchased a Tesla BEV without these. This figure is close to the number reported by (Tal and Nicholas, 2016), which is currently not published, who find that 86.1% of a sample of more than 540 adopters would have still purchased a Tesla without the US\$7,500 tax credit. The incentives were part of the purchase decision for 8/39 of adopters in the sample presented in this thesis, which is not an insignificant number. These findings support the suggestion, in chapter 9, that these incentives are not important for high-end adopters.

Based on the evidence in this chapter the current purchase incentives available for high-end adopters could be changed with little affect on the adoption of electric vehicles. Entirely removing the incentives for high-end adopters in California could only result in a 20% reduction in the number of Tesla BEVs according to the data in this chapter or a 13.9% reduction according to (Tal and Nicholas, 2016), whose analysis is more statistically valid due to their large sample size. This may not be desirable as there is still a large number of BEVs and this would be detrimental to growth of the early market. The adoption of Tesla BEVs is also clearly beneficial to the entire electric automobile market, with the vehicles receiving much media attention hence attracting more consumers to BEVs. The company also has a goal of cost reductions and the production of a mass market BEV, which will results in more sales, increasing the BEV market and also contributing to the Californian economy. It

is indeed easy to argue the merit in encouraging the adoption of the vehicles with financial incentives. However, with many consumers not being motivated by these incentives and some merely using the incentives to buy a more expensive version of the vehicle the incentives do appear to be misplaced. An income cap or perhaps vehicle price eligibility cap would be more appropriate, as was suggested in (Deshazo et al., 2014) The purpose of either of these would be to exclude those adopters who are not influenced by the incentives from getting them, but those who are influenced would still receive them. This would make the incentives more cost effective and efficient. The monetary savings could be invested into other BEV market support activities, for example providing greater support to lower-income buyers, developing more charging infrastructure, or even supporting the used market for BEVs.

The results in this study indicate that the way in which a BEV is recharged is viewed as beneficial by early adopters. This is contrary to much of the existing literature which suggests that BEV recharging is a negative attribute of the vehicles due to long charging times, the difficulty of finding charging outlets and more complex and incompatible with drivers existing experiences (Campbell, 2014a; Carley et al., 2013b; Larson et al., 2014). Home charging is beneficial compared to ICEV refuelling because it is more convenient, saves time, is easier and because drivers see refuelling stations as poor environments. They prefer recharging at home, meaning they don't have to visit refuelling stations and each morning when they get into their vehicles it is always fully recharged. Therefore the refuelling style of a BEV should not be viewed as a negative attribute of BEV, it is only a psychological barrier that requires a behaviour change, which is easily made. Nevertheless, it should be

acknowledged that this is of course only true for vehicle owners with off street parking on a driveway in a garage. Potential adopters in blocks of flats may see themselves excluded from these charging opportunities.

This study of high-end BEVs with ranges of more than 200 miles found that home recharging was the most significant benefit of owning a BEV, yet it was only a motivational factor in adoption for 5 interviewees. This suggests that consumers are not aware of this benefit prior to taking ownership of their vehicles. This is potentially due to the common conception that BEVs refuelling is more challenging than ICEV refuelling. This situation could be avoided by automotive OEMs promoting this benefit to consumers so that they are aware beforehand. This may well attract more consumers to the vehicles, as they no longer see BEV recharging as a shortcoming of the vehicles.

The benefit of home refuelling has not been emergent in any studies of consumers who drive 100 miles BEVs. One study did mention it as a potential benefit, though (Turrentine et al., 2011). This is due to low-end BEVs being slightly more restrictive to adopters due to their short ranges, and this can lead to discontinuance, as discussed in (Hardman et al., 2016). Clearly this is detrimental to the market; longer range low-end BEVs are needed in the market place to prevent this. When transitioning to FCVs the lack of home refuelling possibilities, though, may create a distinctive market entry barrier. This will be discussed later in this thesis.

### **10.8.1 Policy Implications**

Many governments are promoting the market introduction of BEVs due to their environmental, economic and societal benefits. One strategy that is currently being

employed is the roll out of BEV charging infrastructure in order to encourage adoption of the vehicles. In some cases the use of this infrastructure is free of charge. In this study no adopters stated that free public charging as a reason for the adoption of their BEV, and only 2 people mentioned this as a benefit of ownership of their vehicle. Therefore in this sample of high-end BEV adopters it does not contribute to consumer purchase motivations and their benefits of ownership. It is highly likely that this situation is different for adopters of low-end BEVs, which have ranges of 100 miles or less. Therefore public charging infrastructure may be important for this market at present. However, beyond 2018, 200 miles worth of range is likely to be accessible in low-end BEVs as well as high end BEVs. When the BEV market is dominated by these vehicles free public charging infrastructure will become less important, and may not be essential for continual market growth. In order to promote the introduction of BEVs policy makers should seek to incentivise their adoption with interventions that are utilised by early adopters, and do not become redundant in the future. One example of this is the use of HOV lanes. Only 2 adopters indicated that they purchased a BEV to access HOV lanes, whereas 14 state these as a benefit of ownership. Therefore they are an intervention that is used by BEV adopters. Promoting HOV lanes may result in more people adopting the vehicles to make use of these lanes, and it will also contribute to repeat purchases due to the benefit experienced with the previous vehicle.

### **10.8.2 Limitations**

In the same way as a questionnaire survey there could be a sample bias in the interview data presented in this chapter. However, the socio-economic profile of

respondents in this chapter is the same as in the questionnaire survey sample and the UC Davis sample. This again suggests that the adopters in this chapter are representative of early adopters.

A significant finding presented in this chapter was that the purchase incentives available off the price of a high-end BEV are not important for this group of adopters. The numbers recorded here may not be statistically significant due to the sample size of 39 people. This is an acceptable sample size for interviews, but is not the same as a statistically significant sample of questionnaire survey responses. Therefore the findings are only indicative of a trend and do not report exact numbers. The finding is however backed-up by UC Davis data that was presented at the TRB 2016 annual meeting. Again the author of this thesis was able to compare the data in this chapter to UC Davis data. The UC Davis data asked interviewees to describe their purchase behaviour in absence of the federal tax credit (\$7,500 incentive). Respondents were able to answer 'will buy a BEV', 'will buy an ICEV' or 'will not buy a new car' in the absence of the federal tax credit. This data found that 86.1% of their sample would have still purchased a high-end BEV. This number is higher than the number reported in this chapter, this is for two reasons. First it is due to the data being more statistically significant than in this chapter. Secondly it is because the interviewees in this chapter are considering the impact of US\$10,000 worth of incentives, whereas the UC Davis data asks respondents to consider the impact of only \$7,500 of incentives. This would mean that it has a lesser impact on the purchase decision due to it being a smaller sum of money. Both of these data sets therefore suggest that the incentives are not important for the majority of adopters of high-end BEVs.



# CHAPTER 11

A qualitative investigation into early adopters attitudes toward fuel cell vehicles

# **Chapter 11 A qualitative investigation into early adopters attitudes toward fuel cell vehicles**

## **11.1 Introduction**

So far this thesis has not directly considered consumer attitudes toward FCVs, rather it has looked into how historical innovations and the BEV achieved market entry success. This chapter is the first of two that will directly consider the consumer adoption of FCVs. In doing so it aims to build a greater understanding of how consumers perceive the vehicles. FCVs are approaching market entry, with recent developments by some of the worlds largest automotive companies meaning there are now commercial products on the market. 1,500 orders have been made for the Toyota Mirai in Japan and 179 FCVs are deployed in California at present (California Air Resources Board, 2015). Yet to date, research into consumer attitudes towards FCVs has been limited. This was mentioned in Chapter 3 and this situation is potentially detrimental to their successful market entry. The purpose of this study is not to build a representative sample of what the market for FCVs is, but to understand what some of the potential barriers to their adoption by consumers are. By understanding these barriers policy makers, academics and automotive OEMs will be able to work towards overcoming them. The methods used in this chapter are the same as in Chapter 10. The data was gathered using in-depth qualitative interviews with a sample of high-end BEV early adopters. The results in this chapter are taken from the second part of those interviews which explored the interviewees attitudes toward FCVs.

The data collection and analysis method used in this chapter is the same as in chapter 10 meaning it is the use of in-depth interviews which were analysed using grounded theory analysis in NVivo. The interviewees within this sample are all early adopters of AFVs, specifically high-end BEVs. This sample was chosen, rather than a sample of the general population, for a number of reasons. Firstly the general population has been shown to have a low awareness of FCVs and BEVs (Campbell, 2014a; O'Garra et al., 2005), and also a low willingness to adopt the technology (Campbell, 2014a). Members of the general population are also not representative of early adopters (Rogers, 2003). The sample of BEV early adopters was therefore chosen because they are more likely than later adopters to buy new technologies, having clearly demonstrated this with actual purchase behaviours. Therefore these consumers are likely to be the first buyers of future innovations within the sector (Rogers, 2003). Furthermore, Tesla BEV adopters were chosen because chapter 8 found that high-end adopters are more representative of typical early adopters, having high incomes, high-educations and a high number of household vehicles. FCVs are expected to be expensive in initial market entry which is a shared trait with Tesla BEVs (Hardman et al., 2013; Toyota, 2015). It was therefore hypothesised that high-end BEV adopters would have good awareness and knowledge of FCVs, and as early adopters their opinions are more important and relevant than the general populations.

Making comparisons between FCVs and the Tesla Model S with a 270 mile range is also valuable, when FCVs become more commercially available BEVs with ranges of 200 miles and above will be more numerous, with Tesla, Honda, Ford, GM, Audi, Porsche, BMW and Nissan all indicating that they will introduce BEVs with ranges of

200 miles by 2018 (Car Magazine, 2015a, 2015b; Chevrolet, 2015; Green Car Reports, 2015a, 2015b). Therefore FCVs are likely to be compared to BEVs with higher ranges than they are compared to at present, this will clearly have implications for their success as one of the key benefits of a FCV is its long range, along with faster refuelling.

## **11.2 Results**

The sample population in this chapter is the same as Chapter 10 and was discussed in detail there. Chapter 10 discussed in detail the reasons for purchase of a high-end BEV and the benefits of owning one. They are mentioned here very briefly as they are in some way related to consumer attitudes toward FCVs as the remainder of this chapter will show. The main reasons for the adoption of a high-end BEV were due to their high performance, high technology and low environmental impacts, and to a lesser degree because of oil independence. The main benefits of owning a high-end BEV are due to the vehicles ability to be recharged from home, their high performance, low running costs and low maintenance.

### **11.2.1 Barriers to the Adoption of Fuel Cell Vehicles**

All 39 interviewees are aware of FCVs, out of these, 35 have good knowledge. This is due to the interviewee's high level of education, careers in technical professions and because they are involved in AFVs, having adopted BEVs, or because they are located close to areas where FCVs are being rolled out. Interviewees are aware of some of the current FCVs being developed, they are aware of hydrogen infrastructure roll out in California, and other issues such as hydrogen generation. This high level of knowledge means that exploring the barriers to their adoption

resulted in more insightful data than would be gained from members of the general public. In total 12 different barriers emerged, these can be seen in Figure 11.1. Whether or not these are technical barriers to FCV adoption is not important, these are what consumers themselves perceive to be barriers and these perceptions are more important than technical considerations when it comes to consumer adoption. Of the 12 barriers, 5 emerged as prominent themes during the interviews. These were related to infrastructure, the source of hydrogen, home charging, cost, and safety issues. The highest number of barriers mentioned by a single interviewee was 8. Most mention far fewer and the average number of barriers mentioned by respondents is 3. Only 1 interviewee did not state any barriers to adopting a FCV, this was due to a low level of knowledge of the vehicles.

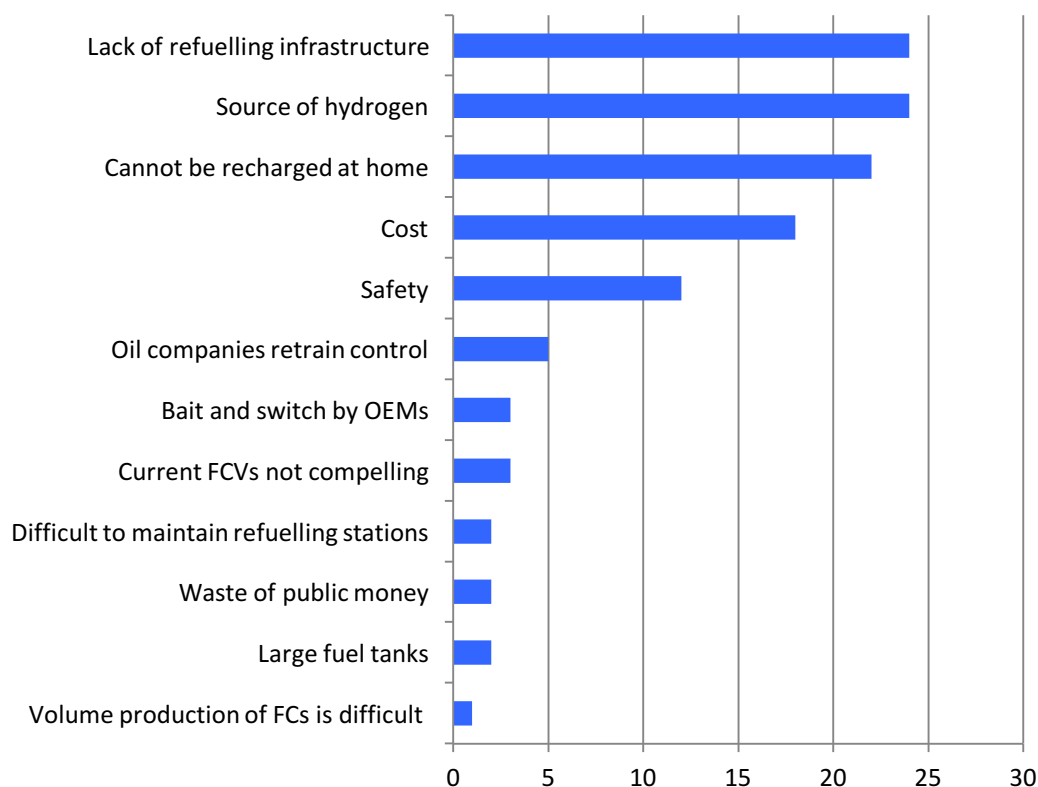


Figure 11.1: Count of early adopter barriers to the adoption of a fuel cell vehicle as reported by interviewees of this study (N=38).

### 11.2.2 Infrastructure

The joint most common barrier mentioned by 24 interviewees is related to hydrogen infrastructure. 23 state that there is no refuelling infrastructure, and 4 state that there is no distribution infrastructure. Therefore 3 interviewees highlight both lack of refuelling infrastructure and lack of distribution infrastructure. The lack of refuelling infrastructure is a barrier as consumers would be unable to conveniently refuel their vehicles. At the time of undertaking this study there were 8 operational hydrogen refuelling stations in the state of California. Some interviewees made comparisons between the abundance of petroleum refuelling stations, or the ease of access to electrical outlets for BEV recharging. Interviewee 11 made a comparison between hydrogen infrastructure and the ease of locating an electrical outlet for a BEV; *“They [hydrogen refuelling stations] are not everywhere, and electricity, electric outlets are.”* They therefore believe that owning a FCV would be less convenient than owning a BEV. Interviewees stated that for early adopters of FCVs it will be more challenging to refuel a FCV than it was for early adopters of BEVs. They believe that the adoption of a FCV would lead to them having range anxiety, as they would be unsure of where they would be able to refuel their vehicle.

*“For the early adopters it’s going to be, just as hard as it was, worse than it was for electric cars, because there is very little infrastructure. I saw a presentation from someone who was building out the hydrogen refuelling infrastructure, and I said that’s back to worrying about range and everything else.”*

Interviewee 14

Interviewee 33 made a comparison between a FCV and a natural gas vehicle. Their brother currently drives a natural gas vehicle, and observations of their brother's experience led them to believe that it would not be convenient.

*"I am not interested in searching out anything. Finding charge points is bad enough right now. I am not interested, and I also didn't consider getting a natural gas vehicle just because there are so many fewer choices for refuelling."*

Interviewee 33

Other interviewees didn't make any comparisons between different fuelling infrastructures; they simply state that there was currently a lack of infrastructure.

*"When you run out of hydrogen where are you supposed to get your car filled up, there are virtually no places to go hydrogen up your car."*

Interviewee 16

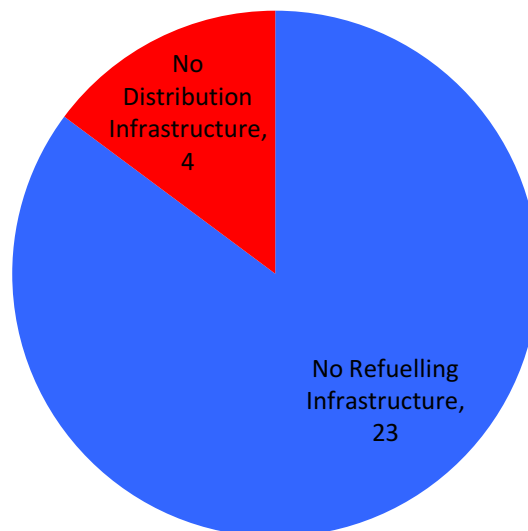


Figure 11.2: Breakdown of infrastructural barriers to fuel cell vehicle adoption (N=24).

### 11.2.3 Hydrogen Source

24 interviewees mentioned the way in which hydrogen is sourced as a barrier, a breakdown of which can be seen in Figure 11.3. The most common reason was

because hydrogen is, by their understanding, mostly sourced from fossil fuel sources.

16 interviewees believed that hydrogen being sourced from fossil fuels is negative.

*“If you are going to have a fuel cell powered by a hydrocarbon then you’re not really advancing the ball sustainability wise. How many dinosaurs are you burning to get that hydrogen?”*

Interviewee 33

15 interviewees believe that the conversion of fossil fuels or water to hydrogen via steam reforming or electrolysis is inefficient. Interviewees believe that even when electrolysis of water is used to generate hydrogen there are significant energy losses during the process, and that this electricity could be used to charge a BEV. 9 interviewees state that sourcing hydrogen from fossil fuels doesn’t make sense. They believe that more CO<sub>2</sub> emissions are released during the production of hydrogen, and they disagree with the use of fossil fuels for ecological reasons such as oil spills. Interviewee 14 mentions these issues, stating that hydrogen is worse for the environment than recharging of a BEV, and that it has an inferior well to wheel efficiency;

*“Most of the hydrogen comes from refined natural gas and so we’re actually finding that it’s more detrimental to the environment than people were thinking, there is a lot of gaseous emissions during the drilling and everything else, so when you count the wheel to well effect you could almost fill up [a BEV] with coal fired electricity and be better off.”*

Interviewee 14

3 interviewees believe that using hydrogen, as an energy carrier for the transportation sector is inflexible. Their perception is that hydrogen can only be generated from a small number of sources, but electricity can be generated using any energy source. Interviewee 39 stated *“electricity is fungible, hydrogen isn’t”*. 2 interviewees believe that using hydrogen as a fuel may consume water, which at the



time of undertaking this study was in short supply in California due to a multi year drought.

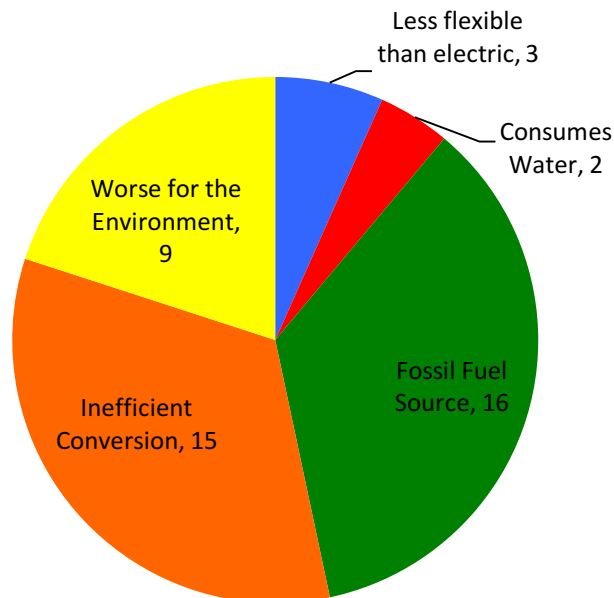


Figure 11.3: Breakdown of reasons related to the source of hydrogen as a barrier to fuel cell vehicle adoption (n=24).

#### 11.2.4 Home Charging

As was previously mentioned the refuelling style of a BEV is viewed as a benefit of high-end BEVs. 22 interviewees mention the inability of FCVs to be recharged at home as a barrier. Interviewees are unwilling to go back to a refuelling style that means they will be required to take a detour to a filling station, and then stand there for 5 minutes to refuel. Interviewees believe that the benefit of FCVs being refuelled in 5 minutes is not advantageous in comparison with being able to recharge at home, and that all that is needed is for consumers to get used to the idea of charging at

home. Interviewee 1 made the comparison between plugging in a mobile phone at night and recharging a BEV;

*“My view is that people will revise their view of what is normal, just like they have with the phone, and they have accepted it, it wasn’t easy for people early on, you had to remember to plug in your phone. I think before fuel cells get their momentum people will have accepted the new fuelling model. So I don’t think fuel cell vehicles will make it. I think home charging will win over fuel cells.”*

Interviewee 1

Interviewee 4 did a verbal calculation of how many times a week they would have to visit a hydrogen station, they stated; *“For me you know that would be maybe every 3-4 days or so. It would certainty be more of an inconvenience.”* Home refuelling did not emerge as a reason for the adoption of a Tesla, it is a benefit which consumers only realise once they have experienced the vehicle. Therefore this may not be a barrier for ICEV drivers, as they haven’t experienced the convenience of being able to recharge a vehicle at their home. It is however a barrier for people who have adopted a BEV, especially a high-end BEV.

### **11.2.5 Cost**

18 interviewees believe that there are cost issues related to FCVs. A breakdown of each reason related to cost is shown in Figure 11.4. The most prominent of these is due to interviewee’s perception that hydrogen refuelling would be more expensive than refuelling a BEV. Currently in the US, the cost of hydrogen is US\$13.60/kg meaning it would cost US\$68 to refuel a FCVs 5kg hydrogen tanks. The cost to refuel a Tesla Model S is around US\$8.18 when refuelling from home, based on electricity cost of 8.67c/kWh (SMUD, 2015), the 85kWh Tesla Model S with a charge efficiency of 90%. Assuming a driving range of 312 miles for a FCV and 270 miles for a Tesla Model S, these figures would mean that the fuel costs per mile would be US\$0.21 for

a FCV and US\$0.03 for a Tesla BEV. Despite the fact that they did not adopt a BEV to save cost, the fact that a FCV would cost more to run is a shortcoming and a deterrent. The low running costs are also a reason for high-end adopters willingness to continue with BEV ownership in future vehicle purchases, as was shown in chapter 8. These running costs may not be a barrier for ICEV drivers, as the cost of hydrogen filling may be similar to that of an ICEV. However unless hydrogen refuelling is cheaper than petroleum refuelling it won't emerge as a benefit of the vehicles.

6 interviewees believe that it will be expensive to build a hydrogen infrastructure. Interviewees do not believe that this expenditure is necessary; they are also concerned that the infrastructure is being constructed with financial support from the state of California. 5 interviewees perceived FCVs as being too expensive. Finally 3 interviewees believe that it is too expensive to generate hydrogen. Interviewee 1 sums all of these concerns up, their perception is that hydrogen fuel is more expensive, hydrogen is more expensive to produce, the vehicles are more expensive, and it is costly to build a hydrogen infrastructure;

*“The fuel is more expensive, its much more expensive to produce than to just use electricity from the grid. And the vehicle is more expensive, and the stations are going to cost a couple of million each. Economically it makes no sense.”*

Interviewee 1

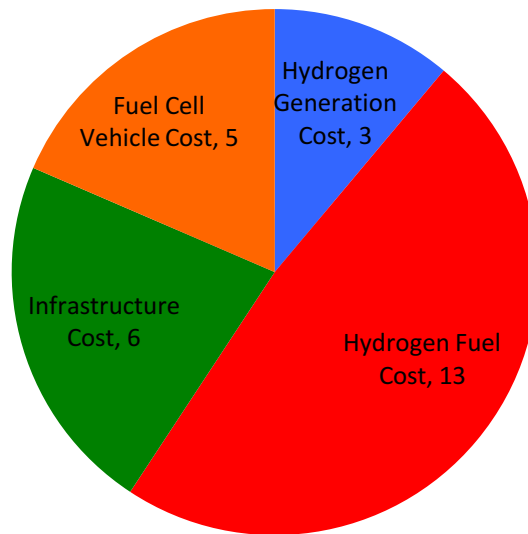


Figure 11.4: Breakdown of cost related barriers to fuel cell vehicle adoption (n=24).

### 11.2.6 Safety

Safety is perceived as a barrier to adoption by 12 interviewees. Safety concerns are related to hydrogen being combustible or due to the 700 bar (10,000 PSI) hydrogen tanks. One respondent who raised safety concerns states that it is just an image related problem; *“Its probably no more dangerous than a normal car. All cars have various safety issues. But the image will scare off quite a few people”*. Most of the concerns, though, were related to the tanks storing hydrogen within the vehicle;

*“I am a little bit worried about having a very high-pressure tank in the car.”*  
Interviewee 38

*“I know the hydrogen is highly pressurised, as a consequence all you have to do is breach that thing and you are going to have a fire.”*  
Interviewee 31

Interviewee 11 and 14 are concerned that hydrogen is explosive at a wide range of gas mixtures, both had heard that if hydrogen leaks when a FCV is parked in an enclosed space it has the potential to be explosive if exposed to an ignition source.

*“From what I’ve heard you really shouldn’t park it in your garage. At least I’ve read that you were supposed to keep it parked outside.”*

Interviewee 14

### **11.2.7 Other Barriers**

The remaining 7 barriers to entry were less prominent, so they are only briefly discussed. Some interviewees are opposed to the idea of a refuelling infrastructure that is dominated by oil companies, which they see as no change from the status quo. They believe that if they were to drive a FCV they would still have to refuel at stations owned by oil companies, something that they are opposed to. 3 interviewees have experience with a FCV, these interviewees perception after driving one is that they don’t have any compelling features over a BEV. 3 interviewees believe that FCVs are just a marketing tool, know as ‘Bait and Switch’ which was being used to distract consumers attention away from BEVs, by promising FCVs that will be launched in the future. This means consumers will continue to purchase ICEVs until FCVs become available, thus allowing OEMs to continue with their most profitable business, which is selling ICEVs. They are therefore suspicious of OEMs offering the vehicles, so are unwilling to accept them. 2 interviewees believe that hydrogen fuel tanks would be large and compromise internal space of a vehicle. 2 interviewees believe that hydrogen infrastructure and FCVs are a waste of public money, these are aware of investments by the State of California into a hydrogen infrastructure. Finally 2 interviewees believe that stations are difficult to maintain and had heard

reports of refuelling stations being out of order for example (Green Car Reports, 2015c). Whether or not these reports are accurate is irrelevant, as it still impacts consumer attitudes. Finally one respondent thought that high-volume production of FCVs would be difficult, and they had heard that Toyota had planned on producing 3000 vehicles per annum, a rate at which the interviewee believed was too low to achieve a mass market.

### **11.3 Demand for Novel Fuel Cell Vehicle Attributes**

#### **11.3.1 Vehicle-to-Home Power**

One of the novel features of a FCV is its ability to provide vehicle-to-home power. It has been proposed that the vehicles can provide power in the event of a power outage or blackout. With full tanks 150 kWh of hydrogen can be on-board the vehicles, this is enough energy to power a house for around 3-7 days depending on demand (Toyota, 2015). Interviewees are interested in this feature, out of 36 interviewees asked, 15 (41.6%) said they would purchase this feature on a vehicle. A further 14 (38.89%) would maybe purchase this feature, but want to know more before they could properly make a decision, 7 interviewees are not interested in this feature. Interest in this feature came about for a number of reasons. Firstly some interviewees live in remote coastal or inland areas where they experience blackouts frequently, sometimes as often as every 2 weeks, occasionally lasting as long as many hours and some interviewees report power outages longer than a day. These interviewees are interested in order to solve the problems they are currently experiencing with power supply. Some respondent's interest comes about due to them anticipating a natural disaster in the future. The most common reason is due to

the risk of a major earthquake, interviewees believe that if this does occur they could be without power for a number of days. In these cases the ability of the vehicle to provide emergency home power is viewed as valuable.

The 7 interviewees with no interest in this feature either report no power outages in as long as they are able to remember or that any power outages they do experience occurred during the daytime when they are not at home. These interviewees said that they are only aware of these power outages because *“the clock on the oven was flashing”*. These interviewees also make no mention of the potential for a natural disaster causing the electricity grid to go down. 2 of these interviewees are not interested in this feature for another reason, they believe that an emergency power system should be 100% available, and if the feature is installed in a vehicle it is possible that the vehicle could not be home when the power outage occurs.

The interviewees who are interested or maybe interested in this feature are willing to pay between US\$500-\$10,000, the mean is US\$2,895 and the median value US\$2,250. Interviewees calculated these values in two ways, firstly they made comparisons between the cost of an existing ICE generator and stated that they would be willing to pay the same amount of what that would cost. Secondly interviewees calculated the amount they believed that such a system could cost to install on a vehicle, and suggested values based on their assumptions.

### **11.3.2 Range**

Another attribute of a FCV that is being promoted by OEMs is its range. The range of a FCV is greater than the range of any current BEV at between 300-360miles (Toyota, 2015). Interviewees in this study report vehicle ranges of between 150 and

275 miles from their BEVs. These figures are reported range and not based on US EPA calculations, or manufacturers calculations. Mean reported range is 232 miles and the medium 237 miles. 38 interviewees were asked if they would like more range, of which 16 (42.1%) indicated that they would, 4 (10.5%) maybe would like more range and 18 (47.4%) believe the current range of their vehicle is enough and they do not desire any more range. The 20 interviewees who want or maybe want more range desire ranges of between 225 and 500 miles. The ones who desire ranges of 225 miles currently have reported ranges of close to 200 miles. The mean desired range is 330 miles and median 325 miles. These ranges are in the same region of the range of a FCV, meaning there does appear to be consumers who desire the range of a FCV.

#### **11.4 FCV Purchase Intentions**

All interviewees were asked if they would purchase a FCV. Of these 3 (8%) indicated that they would, however this was dependent upon cost reductions and more infrastructure development. A further 7 would maybe purchase a FCV, but also had concerns related to the barriers discussed above. 29 (74%) interviewees indicated that they would not adopt a FCV for reasons related to the barriers given. These interviewees all intended to continue with BEV ownership with future vehicle purchases.

#### **11.5 Conclusion**

This chapter has revealed more barriers to the adoption of FCVs than any previous studies, which only identified 2 or 3 barriers to adoption, this is due to the use of in-depth qualitative interviews allowing all possible barriers to be uncovered. But also



because the sample consists of automotive early adopters who are more informed about these issues than members of the general public. 12 barriers emerged in total and 5 of these emerged as prominent. These barriers were lack of infrastructure, the source of hydrogen, not being able to charge FCVs from home, cost, and safety issues. Lack of infrastructure, safety concerns and cost have been previously mentioned in the literature (Ball and Wietschel, 2009; Chalk et al., 2000; Huijts et al., 2012; Keles et al., 2008; Melaina et al., 2012; Roche et al., 2010). Home refuelling and the source of hydrogen have not been previously mentioned. These barriers mean that only 8% of this sample would be willing to adopt a FCV in a future vehicle purchase. There are some positive results with this study finding that there is consumer demand for the range of a FCV. Furthermore a high number of interviewees were interested in vehicle-to-home emergency power and were willing to pay between US\$500-10,000 for this feature. However, these two benefits alone do not outweigh the current perceived barriers to the adoption of a FCV, and these will need to be overcome prior to successful market entry.

### **11.5.1 Limitations**

A possible sample bias in this chapter is due to the sample being purposely selected as high-end BEV adopters. This may mean that the attitudes and opinions expressed are not the same as the general populations or low-end BEV adopters. This was the purpose of selecting this sample, but means that some of the barriers may not be barriers to the adoption of FCVs in the event that someone who is not an early adopter of a BEV decides to purchase a FCV. One particular case is the barrier of FCVs not being able to be recharged from home. It is possible that this is not a

barrier to the adoption of FCVs for consumers who have not experienced a BEV. Nevertheless, it does suggest that consumers will not transition from BEV ownership to FCV ownership.

The sample size in this chapter is small compared to a sample that could be gathered with a questionnaire survey. The data is useful in exploring topics in-depth but it does not yield statistically significant results. There is currently no existing data in published or unpublished form meaning comparisons are impossible. Therefore, in order to understand if the trends reported here are representative of all early adopters of BEVs a future study should aim to gather data on this topic using a questionnaire survey. The results gathered in this study could help in informing the questions that should be asked in that survey allowing the same topics to be explored. The survey should be targeted towards high-end and low-end BEV adopters, but could also include a sample of the general public in order to understand how the attitudes of these three groups of people compare. This would allow corroboration of the data in this chapter and an understanding of if the general public also see these barriers as a concern.

# CHAPTER 12

Consumer attitudes to fuel cell vehicles  
post trial in the United Kingdom

## Chapter 12 Consumer attitudes to fuel cell vehicles post trial in the United Kingdom<sup>6</sup>

### 12.1 Introduction

The chapter is the second chapter in this thesis to consider consumer responses to FCVs. In the previous chapter the attitudes of BEV early adopters to FCVs were explored. That chapter provided some useful insights on how consumers perceive FCVs, however, it did not sample people who had driving experience with a FCV. This chapter addresses that shortcoming by gathering empirical data from consumers who have actually driven a FCV. This data is a small sample of 30 participants in a FCV vehicle trial who were surveyed using a verbally administered questionnaire.

FCVs are an innovation. Thanks to Rogers' Theory (Rogers, 2003) it has long been understood that in order for consumers to adopt an innovation, it needs to have 'relative advantage'. This means that an innovation needs to be perceived as better than the technology that it supersedes. If a technology is merely perceived as similar to the incumbent, consumers will not be motivated to change their behaviour and adopt the new technology. This is especially true when an innovation is more expensive than the preceding technology, as shown in Chapters 2, 5 and 6. In order for consumers to adopt a new and more expensive innovation, it must have significant relative advantage or benefits to consumers. FCVs are more expensive than ICEVs and BEVs, therefore they must have distinct relative advantage. This must be clearly perceivable from the point of view of the consumer and not just

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<sup>6</sup> The results in this chapter are based on the publication Hardman, S., Chandan, A., Shiu, E. & Steinberger-Wilckens, R., 2016. **Consumer attitudes to fuel cell vehicles post trial in the United Kingdom**. *International Journal of Hydrogen Energy*, doi:10.1016/j.ijhydene.2016.02.067

encompass societal and environmental benefits that are the concern of policy makers. Innovations that lack relative advantage suffer from slow rates of adoption, and when adoption does occur discontinuance is high (Rogers, 2003).

This chapter presents data from 30 participants in a FCV trial in the United Kingdom (UK). The objective of the study is to assess consumer attitudes toward FCVs with the objective of understanding if the vehicles have relative advantage. In doing so, a greater understanding of the likelihood of successful FCV market entry can be gained and recommendations to increase market success can be made. This sample is unique as it is the first in the UK and Europe to assess the attitudes of people who have driven a FCV. It is only the second study globally to do this, with the first being in the USA in 2009 (Martin et al., 2009). It is also the first study to assess attitudes of consumers who have driven both a FCV and a BEV. This is an important consideration because consumers are likely to have the choice between an ICEV, PHEV, HEV, FCV or BEV with future vehicle purchases. Previous studies have only considered FCVs in comparison with ICEVs, and do not pay attention to the implications of a further choice between a FCV and BEV. This limitation was mentioned by (Roche et al., 2010) who called for FCV research to be conducted in the context of both ICEVs and BEVs. The FCV in this study is the Hyundai IX35 FCV, which was the first commercially available FCV on the market (Hyundai, 2013). The characteristics of this vehicle can be seen in Table 12.1, in comparison to a Hyundai IX35 ICEV.

Table 12.1: Features of the Hyundai IX35 FCV compared to its ICEV counterpart (Hyundai, 2015a, 2015b). Note that in some markets the Hyundai IX35 is marketed as the Hyundai Tucson.

	Hyundai IX35 FCV	Hyundai IX35 ICEV
Price	£53,000	£18,695
Range	369 miles	611 miles
Refuel time	10 minutes	3-5 minutes
Acceleration (0-60mph)	12.5 seconds	11.5 seconds
Top Speed	99 mph	113 mph
Efficiency (mpg equivalent)	51 (US EPA)	44.8 (NEDC)
Fuel running cost (estimate)	22p/mile	11p/mile

## 12.2 Results

### 12.2.1 Sample Population

The socio-economic profile of respondents can be seen in Table 12.2. The average number of vehicles per household is 2.45. This is far higher than the UK average of 1.6. The age of respondents is spread widely with most between 25 and 54. There are a high proportion of males in this study (86.7%), which might simply be due to the type of event they were attending. 61.5% of respondents have a household income of more than £50,000. Level of education is high with 86.2% having received a university education and 62.1% having achieved a postgraduate degree. Respondents' professions are mostly technical such as automotive, aerospace or control engineering along with university academics and some public sector employees. In summary, respondents have a high number of household cars, are mostly male, have high incomes, are highly educated and have technical professions. The sample therefore appears to have the same socio-economic attributes as typical automotive early adopters, based on the results from chapter 8 and 11. It can therefore be safely assumed that the sample taken at the event is also typical of any other sample of automotive early adopters. Indeed, 30% of the sample

has previously owned an AFV including 5 BEVs, 4 PHEVs and 3 HEVs. This suggests that the respondents in this study are indicative of early adopters, therefore their opinions of FCVs may be representative of early FCV purchasers.

To ensure that the FCV trial study is representative of early adopters the t-test and chi-square are used to compare this sample with a sample of actual BEV early adopters from (Hardman et al., 2016). Directly comparable data for income was not available from the BEV survey and therefore is not included here. The t-test compared the means for number of cars in the household and number of people in the household (Table 12.3). No statistically significant differences were observed. Chi-square was used to compare age, gender and highest level of education (Table 12.4). This revealed no significant difference between gender and education. However age is significantly different between samples, with members of the FCV trial being younger on average. This suggests that the respondents in this study are representative of automotive early adopters, however are of younger age, meaning they may become adopters as they become older. It can therefore be safely assumed that the sample taken at the event is also typical of any other sample of automotive early adopters. This makes their opinions of the vehicles more instructive and meaningful, as these types of people will be the early buyers of automotive innovations, such as FCVs, in the future. Indeed, 30% of the sample has previously owned a low emission vehicle, including 5 BEVs, 4 PHEVs and 3 HEVs.

Table 12.2: Socio-economic profile of the respondents in this study (N=30) and socio-economic profile of the sample of BEV early adopters (n=340).

		FCV Trial Sample		Early Adopters of BEVs Sample	
		Count	Percentage %	Count	Percentage %
Number of Cars in household	1	8	27.6	41	12.1
	2	9	31.0	163	47.9
	3	6	20.7	84	24.7
	4	3	10.3	37	10.9
	5	3	10.0	15	4.4
Number of People in household	1	4	13.3	38	11.2
	2	11	36.7	133	39.1
	3	5	16.7	53	15.6
	4	6	20.0	84	24.7
	5	4	13.3	32	9.4
Age	17-24	1	3.3	4	1.2
	25-34	12	40.0	39	11.5
	35-44	3	10.0	86	25.3
	45-54	9	30.0	88	25.9
	55-64	5	16.7	77	22.6
	65-74	0	0	36	10.6
	75-84	0	0	9	2.6
	85+	0	0	1	0.3
Gender	Female	4	13.3	25	7.4
	Male	26	86.7	315	92.6
Household Income	£10,001-20,000	2	7.7		
	£20,001-30,000	1	3.8		
	£30,001-40,000	1	3.8		
	£40,001-50,000	6	23.1		
	£50,001-60,000	2	7.7		
	£60,001-70,000	6	23.1		
	£70,001-80,000	2	7.7		
	£80,001-90,000	2	7.7		
	£90,001-100,000	0	0.0		
	>£100,000	4	15.4		
Highest Level of Education	A Level or Equivalent	4	13.8	42	12.5
	Undergraduate Degree or Equivalent	7	24.1	136	40.6
	Masters or Equivalent	12	41.4	94	28.1
	Doctorate or Equivalent	6	20.7	55	16.4
	Other	0	0	8	2.4



Table 12.3: T-test results comparing the means for number of people in the household and household cars for the FCV trial participants sample and the sample of early adopters of BEVs.

Attribute	Group	Mean	Std. Deviation	Std. Error Mean	T-Test for Equality of Means	
					Sig. (2-tailed)	Mean Difference
Number of people in household	FCV Trial Participants	2.833	1.2888	0.2353	0.956	-0.0127
	Early adopters of BEVs	2.821	1.1974	0.0649		
Number of cars in household	FCV Trial Participants	2.448	1.298	0.241	0.886	0.0282
	Early adopters of BEVs	2.476	0.9878	0.0536		

Table 12.4: Chi-square results comparing the results for gender, age and highest level of education for the FCV trial participants sample and the sample of early adopters of BEVs.

Attribute	Chi-square	df	Significance (p)
Gender	1.365	1	0.243
Age	25.59	7	0.001***
Highest Level of Education	4.481	4	0.345

## 12.2.2 Opinions of Fuel Cell Vehicles

The unbroken bold red line in Figure 12.1 shows how participants perceive the FCV they have just driven. This shows that the brand, image/looks, range, time to refuel, running costs and life style fit of a FCV are perceived as similar to that of an ICEV. The purchase price of a FCV is perceived as being far worse than an ICEV. Interviewee perceptions of performance and fuel economy are slightly superior and environmental impacts are far superior compared to ICEVs. Therefore FCVs perform worse in 1 area, similar in 6 and superior in 3. The relative advantage of FCVs therefore is their high performance, fuel economy and low environmental impacts compared to the incumbent technology.

Figure 12.1 also shows consumer perceptions of BEVs from Chapter 8. This data shows the perceptions respondents have of the BEVs they have acquired compared to ICEVs. The broken green line shows data from low-end adopters (n=185) who are mainly owners of the Nissan Leaf (83.7%), and the broken blue line shows results for high-end adopters (n=155) who are all adopters of Tesla BEVs. This shows that low-end BEVs are perceived as being superior to ICEVs in 5 areas, similar in 2 and worse in 3. High-end BEVs are superior in 7 areas, similar in 3 and worse in none. As Figure 12.1 shows the perceptions consumers have of FCVs mostly fall short of the perceptions adopters have of BEVs. However, there are 2 areas where perceptions of FCVs are higher than those of low-end BEVs. These are range and time to refuel. There is only 1 area where a FCV is perceived as superior compared to a high-end BEV, and again this is range. This is potentially detrimental as it suggests that BEVs may have more relative advantage compared to ICEVs than FCVs do, which could suggest consumers preferentially would adopt BEVs in the future.

In order to understand whether the differences in Figure 12.1 are statistically significant, the T-test is used to compare differences between each BEV sample and the FCV trial sample. FCV trial participants' responses are compared to the data for high-end BEV adopters and then compared to low-end BEV adopters. The results of this can be seen in Table 12.5. The table shows the sample size, mean, standard deviation, standard error and then the results for the T-test equality of mean significance and mean difference. For high-end adopters' the significant difference (Sig. (2 tailed)) for brand, image/looks, purchase price, performance, fuel economy, lifestyle fit and running costs is  $<0.001$ , with low-end adopters perceptions of these being superior to the FCV trial sample. The means for range, time to refuel and

environmental impacts are not significantly different suggesting that consumers perceive these attributes similarly for high-end BEVs and FCVs. For low-end adopters the significant difference for purchase price, range, fuel economy, life style fit & running costs is  $<0.001$ , with low-end adopters' perceptions of these being superior to the FCV trial sample. The means for the attributes performance and time to refuel are significantly different at  $<0.05$ , with performance being superior, but time to refuel being worse for low-end BEVs. The means for brand, image/looks and environmental impacts are not significantly different.

This data suggests that consumer perceptions of FCVs fall short of the perceptions of BEVs. In order for FCVs to be competitive with high-end BEVs they will need improved life style fit, running costs, brand, image/looks, performance, fuel economy and reduced purchase prices. In order for FCVs to be competitive to low-end BEVs they will need improved performance, running costs, life style fit, and reduced purchase prices.

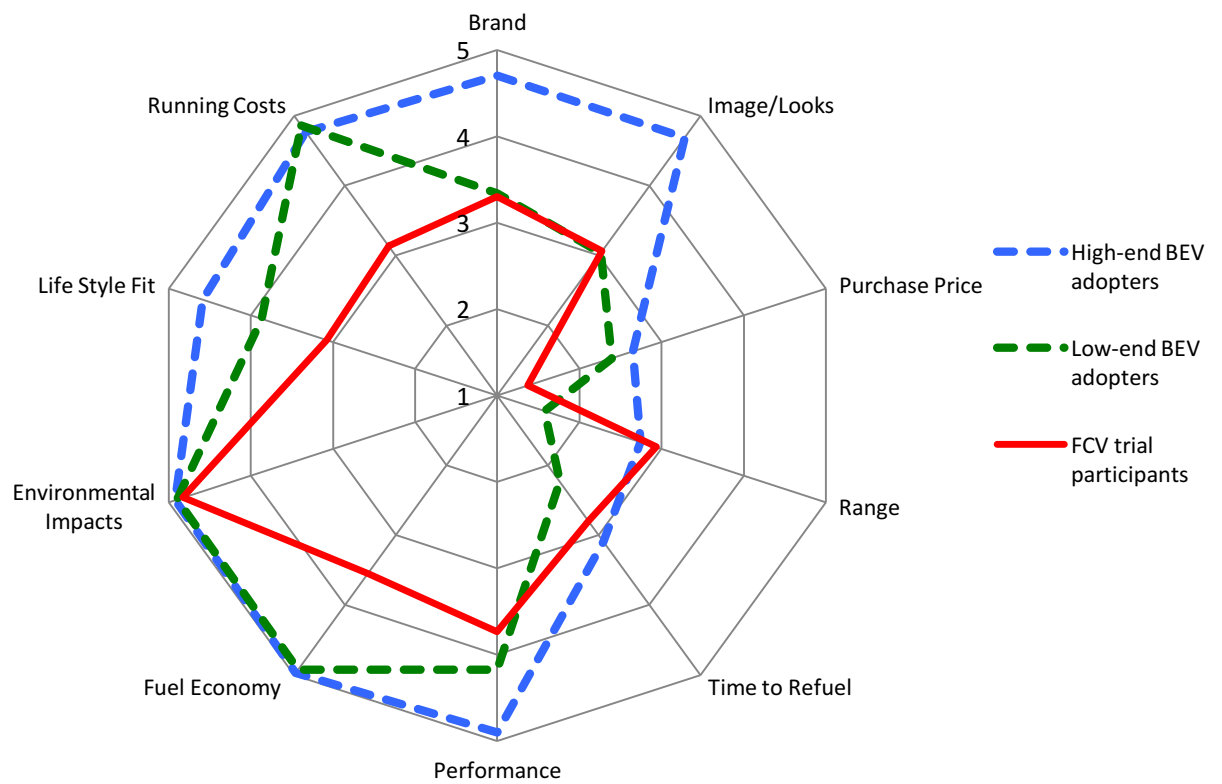


Figure 12.1: Answers to the question ‘Considering each of the following attributes how do you think a FCV (or BEV) compares to an ICEV?’ With answers on a Likert scale of 5= Far Superior, 4= Slightly Superior, 3= Similar, 2= Slightly Worse, 1= Far Worse.

Table 12.5: T-test results for the comparison between the means of the FCV trial study and the high-end BEV sample and the low-end BEV sample. Note that separate T-tests were used to compare the FCV trial data to the high-end data, and then the FCV data to the low-end data.

						T-Test for Equality of Means	
	Group	N	Mean	Std. Deviation	Std. Error Mean	Sig. (2-tailed)	Mean Difference
Brand	FCV Trial Participants	30	3.3	0.6513	0.1189		
	High-end BEV adopters	155	4.703	0.6155	0.0494	<0.001***	1.4032
	Low-end BEV adopters	185	3.341	0.8326	0.0612	0.800	0.0405
Image/Looks	FCV Trial Participants	30	3.067	0.3651	0.0667		
	High-end BEV adopters	155	4.697	0.5741	0.0461	<0.001***	1.6301
	Low-end BEV adopters	185	3.043	0.9826	0.0722	0.898	-0.0234
Purchase Price	FCV Trial Participants	30	1.367	0.7184	0.1312		
	High-end BEV adopters	155	2.69	1.1709	0.094	<0.001***	1.3237
	Low-end BEV adopters	185	2.432	1.0566	0.0777	<0.001***	1.0658
Range	FCV Trial Participants	30	2.933	0.5833	0.1065		
	High-end BEV adopters	155	2.742	1.0497	0.0843	0.334	-0.1914
	Low-end BEV adopters	185	1.573	0.8185	0.0602	<0.001***	-1.3604
Time to Refuel	FCV Trial Participants	30	2.8	0.5509	0.1006		
	High-end BEV adopters	155	3.148	1.4806	0.1189	0.206	0.3484
	Low-end BEV adopters	185	2.276	1.3652	0.1004	0.039*	-0.5243
Performance	FCV Trial Participants	30	3.733	0.8683	0.1585		
	High-end BEV adopters	155	4.897	0.4439	0.0357	<0.001***	1.1634
	Low-end BEV adopters	185	4.178	0.8506	0.0625	0.009**	0.445
Fuel Economy	FCV Trial Participants	29	3.552	0.9851	0.1829		
	High-end BEV adopters	155	4.974	0.2264	0.0182	<0.001***	1.4225
	Low-end BEV adopters	185	4.919	0.4156	0.0306	<0.001***	1.3672
Environmental Impacts	FCV Trial Participants	29	4.828	0.3844	0.0714		
	High-end BEV adopters	155	4.923	0.3699	0.0297	0.209	0.0753
	Low-end BEV adopters	185	4.903	0.3918	0.0288	0.337	0.0751
Life Style Fit	FCV Trial Participants	26	3.077	1.1635	0.2282		
	High-end BEV adopters	155	4.587	0.7367	0.0592	<0.001***	1.5102
	Low-end BEV adopters	185	3.892	0.9664	0.0711	0.002**	0.815
Running Costs	FCV Trial Participants	29	3.138	1.0255	0.1904		
	High-end BEV adopters	155	4.774	0.5872	0.0472	<0.001***	1.6363
	Low-end BEV adopters	185	4.865	0.44	0.0323	<0.001***	1.7269

Figure 12.2 shows responses to the same question as above, however this time respondents were asked to compare a FCV to a BEV. This shows that a FCV is perceived as having similar brand, image/looks, environmental impacts, fuel economy and performance but worse running costs and purchase price. Life style fit is perceived as slightly superior and range and time to refuel are perceived as far superior compared to BEVs. Therefore compared to a BEV the benefits of a FCV are due to longer ranges and shorter refuelling times. This data supports the results found above; therefore the relative advantage of FCVs is due to their range and quick refuelling times, but also due to their performance, improved environmental impact, and fuel economy in comparison to an ICEV.

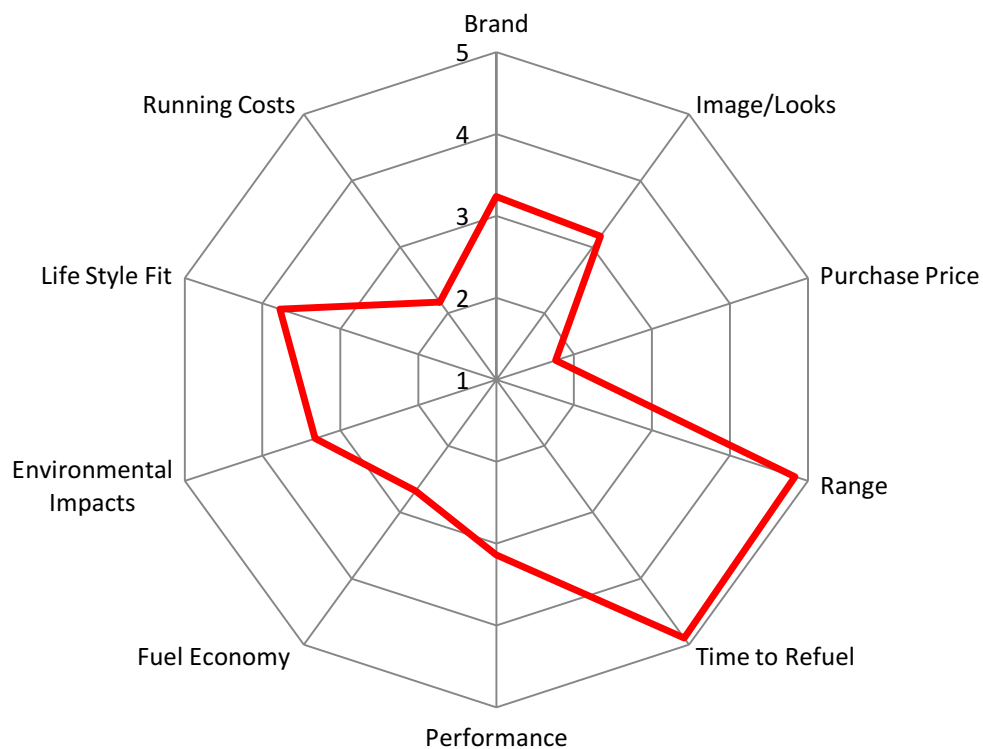


Figure 12.2: Answers to the question 'Considering each of the following attributes how do you think a FCV compares to a BEV?' With answers on a Likert scale of 5= Far Superior, 4= Slightly Superior, 3= Similar, 2= Slightly Worse, 1= Far Worse.

The data presented above is quantitative with a limited number of response options. Therefore FCV trial participants were asked a qualitative question; ‘What did you like about the fuel cell vehicle?’. The purpose of this question was to understand any benefits of the vehicles that the previous question may have overlooked. The emergent topics from this question can be seen in Figure 12.3. The most commonly mentioned benefit was the vehicle’s quietness. Respondents also stated that they believed the range was a benefit, especially compared to a BEV. They perceived the vehicles as representing a new technology. They also liked the acceleration of the vehicle, as they believed that this created a positive driving experience. The low environmental impacts of the vehicles were also perceived as a positive aspect of FCVs.

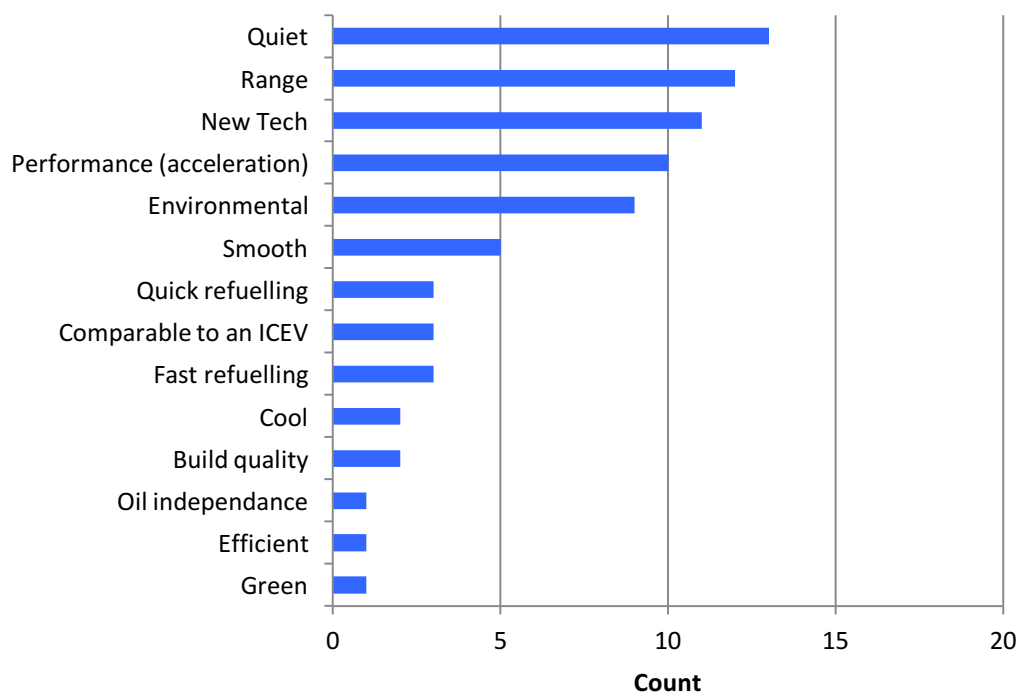


Figure 12.3: Count of responses talking about each issue when respondents were asked ‘What did you like about the fuel cell vehicle?’ (n=30).

Adopters were then asked about the shortcomings of the vehicles with the question 'What didn't you like about the vehicle?' This revealed that the current lack of hydrogen refuelling infrastructure and high purchase prices were the most significant shortcomings of FCVs. The lack of refuelling infrastructure was mentioned by 19 out of 30 and high purchase prices by 18 out of 30 of the respondents (Figure 7.1). This supports the findings of Chapter 11, reiterating the importance of solving these barriers to adoption. Further shortcomings mentioned were high running costs, and the source of hydrogen being perceived as mostly fossil fuels and thus not sustainable.

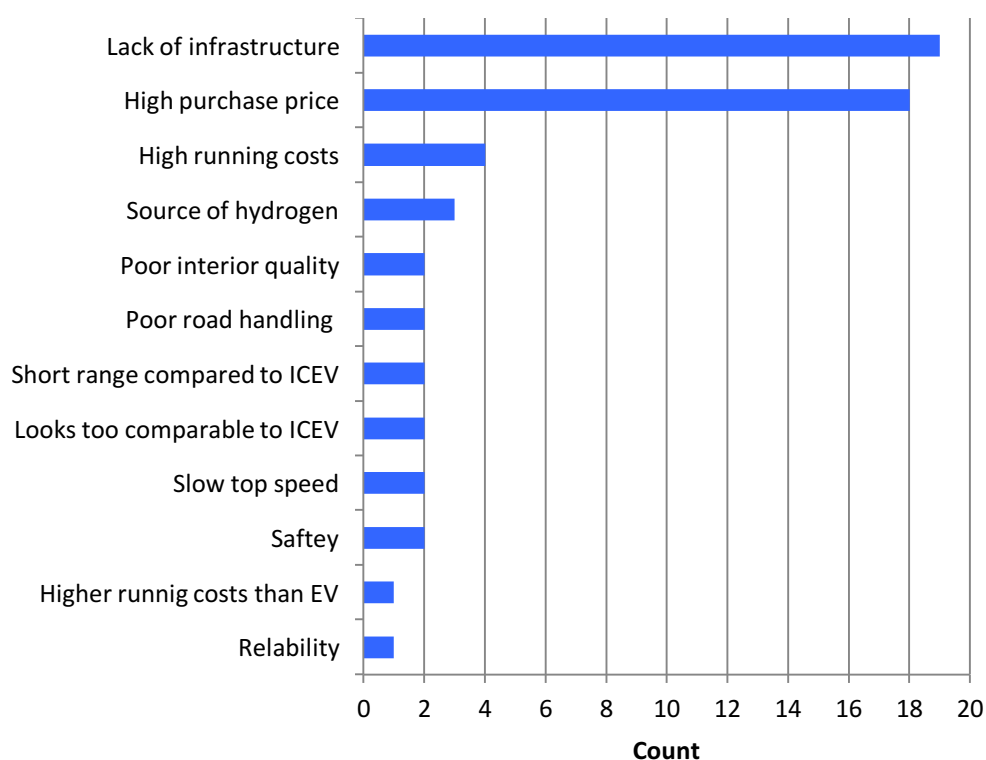


Figure 12.4: Count of responses talking about each issue when respondents were asked 'What didn't you like about the fuel cell vehicle?' (n=30).



## 12.3 Conclusion

The unique situation that FCVs find themselves in today, which is a high priced innovation with two competing vehicle types (ICEVs & BEVs) means that their potential for market entry success is hard to anticipate. In order for consumers to adopt FCVs they must have benefits compared to both of these vehicle types. Low purchase prices or low running costs can form part of an innovation's relative advantage. At present, FCVs are more expensive to purchase compared to an ICEV or BEV although their running costs are expected to be similar to an ICEV. Therefore the vehicles will need functional benefits so that consumers will be prepared to adopt. The results in this study suggest that FCVs have relative advantage due to their low environmental impacts, high fuel economy and performance compared to ICEVs. Trial participants also liked the quietness of the vehicles and the fact that FCVs are a new technology. Therefore FCVs may appeal to environmentally, technologically or performance oriented customers who are drawn to a quiet vehicle with high fuel economy. When compared to BEVs, FCVs have relative advantage in two areas, these are the longer range and shorter time to refuel. FCVs are perceived as having superior ranges compared to low-end BEVs which have ranges of circa 100 miles but also high-end BEVs which have ranges of 270 miles (Nissan, 2014; Tesla Motors Inc, 2015). Therefore FCVs are more superior in this aspect than even BEVs with the longest ranges currently available on the market. Consumers who have adopted BEVs may be attracted to FCVs so that they can drive a vehicle with an electric drive train, which has improved range, and time to refuel compared to their current BEV. However this may not be the case due to perceptions of home refuelling discussed in Chapter 11.

Two significant barriers to the adoption of a FCV emerged from this study, though, the high purchase prices and lack of refuelling infrastructure. These two shortcomings mean that consumer intent to adopt is low with only 10% (3/30) of persons partaking in this study indicating that they would adopt a FCV. Results from the previous chapter found that only 8% of that sample would adopt a FCV in a future vehicle purchase.

### **12.3.1 Limitations**

The most significant limitation of this study is the small sample size ( $n=30$ ) which means that the data is not statistically significant. The data is more representative of consumer attitudes toward FCVs than previous studies. This is due to the fact that the sample has first-hand driving experience of a BEV, but it would benefit from having a larger sample size. Gathering a large sample of people who have driven a FCV would be difficult to complete on one day. This is because of the shortage in FCVs and the difficulty in refuelling them at present due to the small number of refuelling stations. A solution to this could be to repeated the study at the LCV event again in 2016 and beyond using the same vehicles. This method could be used to gradually build up a larger more statistically significant sample.

# CHAPTER 13

Conclusion and implications for fuel cell vehicles

# **Chapter 13 Conclusion and implications for fuel cell vehicles**

## **13.1 Introduction**

Firstly the way in which the three objectives of the study are met is discussed. Then the findings of all of the results in this thesis are used to make recommendations for FCVs and then FCs, this includes stationary power applications. The limitations of this study are outlined, along with potential avenues of future research. Finally, the findings of this thesis are summarised and the the research question will FCVs be adopted by consumers and enter the automotive market? is answered.

## **13.2 Addressing the Objectives**

The aim of this thesis has been met by achieving the following three objectives. The way in which the objectives are met is discussed in detail below.

### **13.2.1 How have innovations historically achieved market entry success?**

Chapters 5, 6 and 7 presented case studies of historical innovations that have achieved successful market entry. These chapters contribute to achieving the first objective of this thesis, which is to examine how innovations have historically achieved market entry.

Based on historical case studies chapter 5 found that upon entering the market innovations that are disruptive are often not recognised by the market leading firms as a threat to their leading position. It was found that innovations are often more

expensive than incumbents when they enter market, sometimes more than 10 times the cost of the existing technology. The high purchase prices are tolerated by the market due to some unique benefits that the innovations possess. Along with these benefits the technologies, due to their early stage of development, have some significant shortcomings. These shortcomings along with high purchase prices mean that the new technologies cannot compete with the incumbents in the mass market, however the unique core and ancillary benefits mean that they appeal to niche markets, where these costs and shortcomings are permissible. Once niche market entry has occurred, the innovation will be able to increase volume sales, reduce costs and work towards solving the technologies shortcomings. Eventually the innovation will begin encroaching on the mass market and start displacing the incumbent, with the innovation becoming the market leader, and the incumbent receding into niche markets. By developing 3 criteria that can be used to identify if an innovation is disruptive this chapter allowed FCVs to be identified as disruptive, which means that the way in which they enter markets will be similar to the way in which historical innovations achieved in the past.

Chapter 6 presented a historical case study of Tesla Motors' whose market entry has a number of similarities with the historical innovations. The technology is more expensive, there are some shortcomings of the technology, but it has core benefits compared to ICEVs. The vehicles were first adopted into niches, and are gradually encroaching into more mainstream markets with their second-generation vehicles. This is due to lower purchase prices and higher volume production of the vehicles. The market entry of Tesla is classified as high-end encroachment. It is high-end encroachment due to high prices and due to the core and ancillary attributes that the

vehicles possess. This market entry strategy was found to be beneficial in comparison with low-end BEV market entry. Because the vehicles are expensive, and have core benefits, they are positioned in a market with comparably priced ICEVs, such as sports cars and luxury saloons. This means that when economic comparisons are made, Tesla BEVs can achieve financial paybacks in around 4 years. Low-end BEVs have lower purchase prices, however they have fewer benefits, which means that when compared to similar vehicles they make less economic sense. Due to their prices being far higher, it takes around 9 years for a financial payback to occur when compared to a similar ICEV. Furthermore despite Tesla Motors selling fewer BEVs than Nissan for example, they have generated more revenue due to purchase prices being higher. This means there is the potential to acquire more revenue to invest into future products through high-end market entry, and this is what they have been doing by investing in their future generations of vehicles.

The final case study chapter 7 reviewed how new infrastructure, for innovations that do not have pre-existing infrastructure, is developed. Studying the development of mobile phone infrastructure provided useful insights for the development of a hydrogen infrastructure. When innovations that require an entirely new infrastructure are introduced to the market there must be some pre-development of the required infrastructure. Mobile phone infrastructure development began before mobile phones were marketed to consumers. Expansions of network coverage pre-date mobile phone market growth, and advancements in mobile phone network capabilities pre-date the introduction of mobile phones compatible with the new capabilities. Finally all stakeholders of the innovation invested into the development of networks, which

included mobile phone producers and network providers, and even the incumbent landline network developers. The findings in this chapter are more relevant for FCVs compared to the existing literature. Previous studies used the example of ICEV refuelling infrastructure which is not relevant due to their being pre-existing petroleum supply. The development of mobile phone infrastructure is more relevant due to their being no pre-existing networks.

The findings from these three chapters indicate that in order for innovations to enter markets and displace incumbents they do not need to have lower purchase prices. If they are more expensive though they must have decisive benefits. They should also be marketed towards niche markets first where early adopters are present. Finally, when innovations are reliant upon infrastructure it should be pre-developed before the innovation will be marketed to consumers.

### **13.2.2      How are battery electric vehicles achieving market entry success at present?**

The second objective of this thesis was to examine how BEVs are achieving market entry at present by understanding the process of consumer adoption of the vehicles. This aim was met in chapter 8, 9 and 10.

In order to meet this objective a number of sub-objectives needed to be explored. The first of these was developing an understanding what types of people are the adopters of the vehicles. Exploring early adopters socio-economic and psychographic profiles allowed this understanding to be gained. Early adopters were found to be mostly male, of a wide range of ages, have a high level of education, have high incomes, work in technical professions, have a high number of household

vehicles and often have more than one BEV or a HEV or PHEV in addition to their primary BEV. They were found to have psychographic profiles similar to what is expected in Rogers' theory.

The unique sample of actual adopters revealed two heterogeneous groups of early adopters, meaning that early adopters of BEVs are not homogenous. Statistically significant socio-economic differences in gender, age, level of education and income were recorded. There were also statistically significant psychographic differences with high-end adopters being more willing to take a risk and having a greater level of empathy for example. This is a direct contradiction to Diffusion of Innovation theory (Rogers, 2003) and is a significant academic implication that goes against the notion that early adopters of new technologies will be the same. This sample is only a sample of automotive adopters, and not early adopters of all innovations, nevertheless these findings may suggest that early adopters of innovations in general are not always the same, especially when the innovation is available at different price points with each one having different attributes.

An additional consideration when investigating the decision to adopt a BEV was examining what premium early adopters had been willing to pay for their vehicles compared to an ICEV. The results in chapter 9 found that high-end adopters paid a premium of \$37,686 on average compared to their previous ICEV. Low-end adopters only paid a premium of \$3,932. These results are the first figures reported based on evidence from actual adopters, with previous studies only investigating what potential buyers of the vehicles might pay. It was hoped that multiple linear regression analysis could be used to explore what the influences on willingness to pay are. The results of this were not conclusive, and for this reason are not presented in this thesis.



However the results did indicate that adopters' opinions of vehicle attributes might be related to willingness to pay. This means that high-end adopters were willing to pay more for their BEVs because their opinions of them were superior compared to low-end adopters opinions and willingness to pay. However it was not possible to break this down to each attribute to show which ones have the biggest influence, due to low levels of statistical significance.

The second sub-objective was to develop an understanding of the motivations for adoption of the vehicles. The data was gathered for high-end adopters only, and this was for reasons outlined within chapter 10. In this chapter it was found that the main motivations for purchase are related to performance, the environment and the high level of technology of the vehicles. Adopters were motivated to purchase a high-end BEV over a low-end BEV due to the longer ranges that the vehicles have. An emergent theme was that financial motivations, in terms of cost savings, were not a reason for adoption for the early adopters of high-end BEVs. Another theme that was explored in detail was the impact of financial purchase incentives in the purchase decision. It was also found that the incentives, which are available when purchasing a BEV, do not influence buyers' decisions. Again this data reveals what attributes of the vehicle have actually lead to consumers buying a BEV, which is more valid than the hypothetical data presented in the literature.

The third sub-objective worked toward understanding the benefits of owning a BEV. This was explored in both the questionnaire survey and the qualitative interviews. The data is concerned with consumer perceptions and not the actual attributes of the vehicles. From the questionnaire survey it was found that high-end BEVs benefit from superior brand, image/looks, performance, fuel economy, environmental impacts, life

style fit and running costs compared to ICEVs. They have similar time to refuel, range and purchase price. According to consumer perceptions low-end BEVs were found to have superior performance, fuel economy, environmental impacts, life style fit and running costs. They have similar brand, image/ looks and worse purchase price, range and time to refuel. The results for high and low-end adopter opinions of their vehicles were compared using the T-test. It was found that there are statistically significant differences in the way in which each group perceives their vehicles, and that high-end adopters believed their vehicles were more superior than low-end adopters did. Further evidence from the interviews supports these quantitative findings, along with additional topics emerging. From the interviews it was found that the way in which a BEV is recharged is viewed as the most significant benefit of owning a high-end BEV. Drivers of these BEVs believed that charging at home was easier, quicker and more convenient than visiting gas stations that they disliked because they believed they are dirty and poor smelling environments. This finding is supported by qualitative data in the questionnaire survey where 37.9% of high-end adopters mentioned home charging as a benefit without any prior ques. Performance and running costs were the next most significant benefits during the interviews. This benefit of home charging is something that has not emerged in any previous BEV consumer adoption studies.

The final sub-objective examined the future purchase intentions of early adopters. This data was gathered during the questionnaire survey and the in-depth interviews. The questionnaire survey found that buyers of high-end BEVs are very likely to continue with owning a BEV and also a BEV of the same brand. Buyers of low-end BEVs were found to be far less likely to continue with owning a BEV and of owning a

BEV of the same brand. Therefore high-end adopters are likely to continue with their decision to adopt, but for low-end adopters discontinuance may occur. The reasons for this are related to the perceptions of the vehicle attributes. As was shown in chapter 8 high-end adopters' opinions of their vehicles are significantly superior compared to low-end adopters' perceptions, and this is the reason for the differences in future purchase intentions. This finding came about thanks to multiple linear regression analysis comparing future purchase intentions with vehicle attribute opinions. It was found that for low-end adopters long charge times are a significant influence on their future purchase intentions, and that reducing charge times whilst also increasing vehicle range would lead to improved future purchase intentions. During the qualitative investigation interviewees were asked about future ICEV ownership for both a primary and secondary vehicle. Indeed, these adopters did not intend to own an ICEV as a primary vehicle. However it was found that a small number of adopters might purchase an ICEV as a secondary vehicle that would entirely be used for leisure. This finding was interesting and relates to chapter 5 where it was found that incumbent technologies do not disappear altogether but they enter niche markets. Therefore ICEVs may enter a niche similar to horse drawn carriages are used for today, being used mostly for leisure and not primarily for transportation.

The in-depth study of the BEV revealed that consumers are adopting this more expensive innovation because the vehicles have benefits compared to ICEVs. It was found that consumers who are adopting BEVs are typically early adopters. Consumers were found to perceive BEVs as having a large number of benefits over ICEVs giving them significant relative advantage. Because of the myriad of benefits consumers are willing to pay a price premium for the vehicles, and generally

speaking the more benefits the vehicles possess the larger the premium consumers are willing to pay. Consumers are highly likely to continue with owning a BEV in future vehicles choices, this is due to the large number of benefits. It was found that some low-end adopters will discontinue with BEV ownership in future vehicle purchases due to low recharge times and short ranges. This situation will be changing and low-end BEVs with ranges of 200 miles are being introduced to the market from the end of 2016. This means that discontinuance may not occur and these early adopters of low-end BEVs with ranges of 100 miles at present will move to low-end BEVs with 200 miles of range.

### **13.2.3 What is the current potential of fuel cell vehicles to be adopted by consumers?**

Chapters 11 and 12 worked towards the third objective, which was to examine the potential for FCVs to be adopted by consumers by understanding consumer attitudes toward the vehicles and understanding any barriers to their adoption.

Chapter 11 gathered data from adopters of high-end BEVs who were asked questions about FCVs. This is the first study in the literature that uses a sample of actual automotive early adopters to understand perceptions of FCVs. Because of this, the study identified more barriers to the adoption of FCVs than have been previously identified. The most prominent barrier is due to the source of hydrogen, which is mostly from fossil fuels meaning it is perceived as worse for the environment and as being inefficient. The second most prominent barrier is due to the lack of refuelling and distribution infrastructure meaning it would be challenging to refuel a FCV. A third reason was because FCVs could not be refuelled at home, like a BEV

could be. Cost was found to be a barrier, this was because of the high purchase prices of FCVs and the high price of hydrogen fuel, meaning the vehicles are more expensive to buy and refuel. Finally perceptions of hydrogen safety are an issue for consumers who perceive the vehicles as being unsafe.

Chapter 12 gathered data from people who have actual driving experience of a FCV. This was the first study in Europe to sample people with experience of FCVs, and only the second globally with the first study being in 2009 (Martin et al., 2009). From this study it was found that the environmental impacts, fuel economy and performance of a FCV is perceived as superior compared to an ICEV. Life style fit, running costs, brand, image/looks, range and time to refuel were perceived as similar with price being perceived as worse. Compared to BEVs FCVs are perceived as having superior range and time to refuel, whilst having similar brand, image/ looks, performance, fuel economy and environmental impacts. The vehicles have worse running costs and purchase price compared to a BEV. This study also gathered barrier to adoption data with the lack of infrastructure and high purchase prices emerging as the most significant, agreeing with the findings from chapter 11.

Some positives did emerge and there may be consumer demand for the ability of a FCV to provide vehicle-to-home power. Consumers may be willing to pay in the region of \$500 to \$10,000 for this feature. There is also consumer demand for the range of a FCV, with BEV adopters demanding a vehicle with ranges of 330 miles on average. The sample of consumers with experience of the vehicles also like the quietness of the vehicles, along with its range compared to a BEV and the high technology nature of the vehicles. Despite these positives intent to adopt a FCV is low within both samples due to the barriers. This leads to the conclusion that, based

on the evidence gathered, the answer to the research question; will FCVs enter the automotive market by being adopted by consumers? is currently no. This is because FCVs are not perceived as being beneficial compared to the incumbent (ICEVs) or competing technology (BEVs). This means that consumers will not choose FCVs when considering their vehicle purchases. This situation could be changed and below recommendations are made which would mean that the barriers of FCVs are addressed, hopefully leading to consumers being more receptive of them.

### **13.3 Recommendations for Fuel Cell Vehicles**

The unique situation that FCVs find themselves in today, which is a high priced innovation with two competing vehicle types (ICEVs & BEVs), means that their potential for market entry success is dependent upon the vehicles being perceived positively by consumers as compared to incumbent and competing innovations. Low purchase prices or low running costs can form part of an innovation's relative advantage. But at present FCVs are more expensive to purchase compared to an ICEV or BEV although their running costs are expected to be similar to an ICEV. High initial purchase prices are not uncommon for innovations and this thesis presented cases of successful market entry by innovations that were more expensive than the incumbent, and the same has been the case for the BEVs in this thesis. The high purchase prices, though, were in combination with significant benefits for consumers, and the presence of these meant that early adopters were willing to pay these higher prices. As the results in chapter 9 show consumers, can be willing to pay a significant premium for zero emission vehicles, especially high-end BEVs.

Therefore this is not a barrier to FCV market entry providing the vehicle has sufficient benefits over the incumbent.

The results in chapter 12 suggest that consumers perceive FCVs as mostly similar compared to ICEVs and BEVs. This may be an admirable technical achievement, especially when considering BEVs and ICEVs have had more years of technological development. However it does not result in the vehicles having relative advantage from the consumer viewpoint, and this is needed in order for consumers to purchase them. In this particular study purchase intentions were low meaning consumer adoption looks unlikely. That sample of data in chapter 11 that is based on in-depth interviews with BEV adopters (n=39) found that only 8% of them would adopt a FCV. Their reasons were related to high costs and lack of infrastructure. Intent to adopt in chapter 12 is low with only 10% (3/30) of consumers partaking in this study indicating that they would adopt a FCV. Another set of data, held by the author of this thesis, which is small (n=9), from consumers in California who have actually adopted a FCV, indicated that of these only 3 (33%) will continue with FCV ownership in future vehicle purchases. The reasons for discontinuance in this sample are due to lack of refuelling infrastructure, but also lack of reliability with existing refuelling stations. 6 out of 9 drivers intended to return to driving an ICEV or switch to a BEV. All of this data indicates that intent to adopt a FCV still remains low and that when adoption does occur discontinuance could be high. Action is needed in order to change this situation, and this can be done through ensuring FCVs have significant relative advantage so that consumers will be willing to adopt the vehicles despite their high costs and lack of infrastructure.

If the barriers to adoption of FCVs identified in this thesis remain, the implications for FCVs will be negative and rates of adoption will likely be low. However, it is possible to remove these barriers in part or full and also develop relative advantage in the vehicles. The way in which this could be achieved is described below.

The most prominent barrier is the lack of hydrogen infrastructure. The development of a hydrogen infrastructure was discussed in (Hardman and Steinberger-Wilckens, 2014) and in chapter 7. It was suggested that pre-developing infrastructure prior to launching FCVs was the best strategy for successful adoption. Without there being some infrastructure early adopters will be unwilling to accept the technology. Therefore infrastructure needs to be pre-developed in order for consumers to adopt FCVs. All stakeholders, including OEMs, policy makers, fuel suppliers, fuel producers and gas companies should invest in this development, as they will all benefit from successful market entry of FCVs. The development of hydrogen infrastructure is a necessity, the market for FCVs will not exist without hydrogen refuelling infrastructure being developed.

Another prominent barrier is due to consumer concerns about how hydrogen is sourced. This can be addressed by firstly using the most energy efficient low emission method for hydrogen generation. Education and outreach will help consumers understand how the well to wheel efficiency of FCVs compares to that of ICEVs or BEVs. The well to wheel efficiency of a FCV can be worse than a BEV in some regions, especially when electricity grids are low carbon, for example in California. However in regions where the electrical grid is still coal based, for example areas in North Midwestern USA, driving a BEV is less beneficial due to the low efficiencies of coal powered electricity generation (Onat et al., 2015; Tamayao et al.,



2015). In these areas FCVs will be more beneficial, as it is possible for them to have greater efficiencies compared to BEVs as hydrogen could be sustainably generated, or imported, meaning it is not generated using electricity from the carbon intensive electrical energy in those areas. Conversely in areas where the electricity grid is low carbon, due to the use of wind, solar and hydroelectric power, FCVs will be less beneficial than BEVs. Hydrogen infrastructure and FCVs should be placed in regions where they have the biggest benefit over BEVs due to there being a carbon intensive electrical grid.

The barrier of home charging can only be partially overcome, but it is possible to increase the convenience of FCV refuelling. Drivers of plug-in hybrid electric vehicles (PHEVs) which have ranges of around 40 miles are able to drive 67.5% of all vehicle miles travelled using the battery alone (Tal et al., 2014). This means that visits to refuelling stations occur at a rate of 1/3 compared to driving a standard ICEV. Therefore if a FCV were to be a plug-in hybrid FCV with a range on battery power of >40 miles it would be possible to achieve the same benefit. This would also mean that the requirements for a hydrogen infrastructure are reduced, as refuelling events would occur less frequently and drivers are not fully dependent upon a sparse infrastructure in the early days of the market. Furthermore, car buyers have previously been shown to be most interested in vehicles that are PHEVs (Axsen and Kurani, 2013), which may help in increasing early market demand for FCVs. This barrier may only be a barrier for BEV adopters though, as this benefit was only realised by drivers after they had adopted the vehicles. Therefore it is possible that this will not be an issue for ICEV drivers, but BEV drivers may be unlikely to adopt a FCV for this reason. This may become more of an issue as the BEV market grows,

which could mean the FCV market becomes eliminated. Even so the recommendation of developing a plug-in hybrid FCV will make the vehicles more appealing to ICEV drivers as it will increase convenience of refuelling, meaning trips to the limited hydrogen infrastructure will be reduced by 67.5% assuming similar driving patterns as the PHEV adopters in (Tal et al., 2014).

Cost is also a barrier to FCV adoption. The cost of building a hydrogen infrastructure and generating hydrogen cannot easily be reduced. Therefore it may have to be continually subsidised in the early stages of market development. The running costs in terms of fuel costs should be lower than that of an ICEV, and close to that of a BEV in order to increase the competitiveness of hydrogen as an automotive fuel. Low running costs did not emerge as a reason for adoption of a high-end BEV, but high running cost might lead to consumers being dissuaded from adoption of FCVs and could reduce the likelihood of continual ownership of the vehicles once adoption has occurred. Indeed BEV adopters have been found to adopt their vehicles due to running cost savings (Caperello et al., 2015). This will attract cost conscious or economically rational consumers to the vehicles. In order to achieve this, policy makers will be required to contribute to lowering the purchase prices of the vehicles. This situation already exists for BEVs and, indeed, for FCVs in many regions. In the UK £4,500 is available off the purchase price of a plug-in car or £8,000 for a plug-in van (these grants are also applicable to FCVs) (Gov.uk, 2016). These incentives are not enough to bring the purchase prices of the vehicles down to a lower cost compared to ICEVs, therefore larger incentives will be required. The cost of hydrogen is currently £12/kg in the United Kingdom, €10/kg in continental Europe and \$13.60/kg in California (FCH2JU, 2016; ITM Power, 2015). This means the vehicles

have comparable or lower fuel costs than an ICEV, but are more expensive to run than BEV. Policy makers will be required to increase subsidies to both purchase prices and the costs of operation so that FCVs have economic relative advantage. High-purchase prices of the vehicles are also a barrier to adoption. However simply stating that FCVs are too expensive is an oversimplification and cost reductions may not lead to consumers perceiving positively enough for adoption to occur. Low-end BEVs are an example of a cost reduced market entry strategy, and indeed more units have been sold compared to high-end BEVs. However less revenue has been generated per unit sale and more worryingly discontinuance by low-end early adopters is far higher than in high-end adopters. A more appropriate strategy would be to increase the amount of relative advantage in the vehicles, in a way similar to high-end BEVs. The high-end strategy has the benefit of consumers perceiving the vehicles more positively compared to ICEVs. As the results have shown this leads to continual ownership of the vehicles being likely which is crucial for the mass-market entry of BEVs. Furthermore by positioning the vehicles in the high-end of the market the vehicles can be more cost competitive compared to ICEVs, as shown in chapter 6. The right combination of attributes within the vehicles will make consumers perceive the cost of the vehicles as less of a barrier. A high cost FCV with superior attributes will therefore be perceived as a better value proposition compared to a low cost BEV with inferior attributes.

Finally, safety was found to be a barrier. Scientists and engineers generally agree that FCVs are safe. However, there does appear to be some consumer concern. Education and outreach will help in addressing this issue. Crash testing FCVs in line with IIHS (Insurance Institute for Highway Safety), NHTSA (National Highway Traffic

Safety Administration), and Euro NCAP (European New Car Assessment Programme) standards will help, as these are organisations and crash test regimes which consumers are familiar with.

This thesis identified some positives for FCVs. There is consumer demand for vehicle-to-home emergency power. Consumers are willing to spend US\$500-10,000 for this feature. Marketing the vehicles in regions where blackouts are more frequent may therefore be a beneficial strategy for FCVs. This attribute of FCVs is currently not available in any ICEV or commercial BEV and therefore this could be a relative advantage of FCVs. However improving the other attributes of the vehicles will also be advisable.

In order to address the barriers for FCV adoption, significant investments will be needed. These investments will need to come from automotive OEMs but also public funds. Investments into new automotive technologies are needed in order to avoid the societal costs that will inevitably occur if the automotive sector remains to be dominated by ICEVs using petroleum. Furthermore the purpose of FCVs is to solve the problems of oil dependence, carbon emissions and urban air pollution. It is possible that the investments required to develop the market for FCVs could result in a greater benefit if invested into other automotive technologies that tackle these problems, for example PHEVs and BEVs. Indeed, BEVs have potentially better well-to-wheel efficiencies compared to FCVs, which results in lower emissions and less import dependency (Stimming and Ramachandran, 2015), depending on the source of primary energy employed in electricity generation and hydrogen production. If policy makers, fuel suppliers and OEMs decide that investments into hydrogen and FCVs are worthwhile activities, they should be targeted to regions where average

daily vehicle miles travelled are high so that consumers demand the range of a FCV. Further to this they should target regions with unreliable grid power supply, which would mean that the benefit of vehicle-to-home emergency power is highly valued by consumers. And the grids should also be largely coal powered as previously mentioned. They should then undertake a joint effort that sees all stakeholders investing in the development of a hydrogen infrastructure in these areas so that the chances for success are highest.

### **13.3.1 Recommendations for Fuel Cells**

FCVs are only one application of FCs, which have the benefit of being scalable meaning a huge number of applications are possible from portable and handheld to large scale power supply to the electricity grid. In the publication (Hardman et al., 2015) further applications of FCs are discussed. The purpose of this publication was to demonstrate that there are applications of FCs where significant relative advantage is present. As opposed to FCVs, whose relative advantage is poor from the perception of consumers, these applications have many benefits.

FCs do not actually offer individual characteristics that no other energy products have. The benefits of quietness, flexibility, quick refuelling times, zero tailpipe emissions and long run times can all be found in other technologies. However, the distinguishing feature of FCs is that they possess a unique combination of characteristics in one package. FCs should be marketed with these in mind, and not just as power providers. Doing this will mean the applications provide more relative advantage. These added benefits of FCs are potentially:

- Quiet operation

- Zero tailpipe emissions
- Long run times
- Can operate in extreme conditions
- Quick refuelling
- Scalability
- Fast start up
- Minimal user intervention
- Low vibration
- Fast deployment/installation
- High fuel efficiency
- 'Green' image
- Fire prevention
- Production of water
- Production of heat

A number of FC applications that utilise some of these benefits have already been developed. German FC Company, SFC Energy, has been successful in selling over 30,000 units of their Direct Methanol Fuel Cell (DMFC) power providers. They initially targeted recreational motorhome users with their 40-105W power providers, which would power some of the electronics on a motor home when electrical power points are not available. These FCs have longer run times than batteries, are quieter than ICEVs and require minimal user interventions, have no vibrations and can be refuelled quickly, and also can be used in regions where ICE generators are prohibited due to regulation (Department of National Parks Recreation Sport and Racing, 2014; National Parks Service, 2014). They have also had success selling personal power providers, and larger stationary units to the defence sector. These units have the benefit of reduced weight compared to batteries meaning that soldiers can carry more pieces of mission critical equipment; they are also silent and have a

limited heat signature. Recently SFC Energy has begun pursuing the industrial sector, and are particularly targeting oil and gas terminals in remote locations. These terminals are typically powered by ICE generators, which require frequent refuelling. Due to the remote locations, this is done using a helicopter, meaning that each refuelling event can cost CAD\$3000-\$5000. The long run times of the SFC unit and the full autonomy means that the number of helicopter trips can be greatly reduced resulting in economic benefits for the user.

The second company discussed in that publication was an American company, Bloom Energy, who produce SOFC stationary back-up power units. These units are specifically marketed toward data centres. The main benefit of the FC back-up power units for data centres is the ability to provide power 100% of the time. A large number of high-profile clients have adopted the power providers to ensure their data centres do not fail. Maintaining power at these data centres is vital to companies avoiding financial loss and technical damage. For example, in 2013 Google.com was offline for 5 minutes in this time they lost USD\$500,000 in advertising revenue. In the same year Amazon.com went offline for 15 minutes and lost between USD\$1-2.5 million in sales, and their share price fell by 10%. FCs are able to remove the risk of websites going offline due to a power outage by providing reliable back-up power supply.

A German company in the early stages of market entry has developed a FC system that builds upon back-up power supply (N2telligence, 2014). Their system can provide this along with heating, cooling and fire prevention. The cathode side exhaust of a FC contains less oxygen than ambient air, around 15% O<sub>2</sub> by volume. At this concentration people are still able to respire but fires cannot start. This unit therefore has 4 benefits for the users. Back-up power and fire prevention reduce the risk of any

losses occurring and the provision of heat and cooling can reduce data centre running costs.

FCs can also be used as aircraft Auxiliary Power Units (APUs), although at present no commercial offerings exist. Boeing and Airbus have reportedly been interested in this technology since 2001 (Peters and Samsun, 2013). The main driver for the use of FCs on aircraft is power provision, but also the production of water and inerting gas (Peters and Samsun, 2013; Pratt et al., 2013; Wiethege et al., 2014). This aids in the reduction of emissions and fossil fuel consumption in air travel, by increasing electrical efficiency and reducing the weight of the aircraft. FCs cannot currently be used for propulsion due to too low power densities of hydrogen storage. They are instead useful for providing auxiliary power (Peters and Samsun, 2013). In addition to power, water and inerting gas, FC APUs can provide heat for wing de-icing, heat and cooling for the cabin and back-up power supplementing the Ram Air Turbine (RAT). Owing to the many uses of the FC and its waste products, in this application the units are referred to as Multifunctional Fuel Cells (MFCs) (Keim et al., 2013; Peters and Samsun, 2013). This is a promising application of FCs that might be a distinctive future market.

### **13.4 Limitations and Future Research**

Despite this thesis presenting data from a number of different sources there are limitations and future research is needed in order to understand the potential for consumer adoption of FCVs. This thesis also considered the adoption of BEVs and there are some areas of research that still need addressing in order to fully understand that related issue.



Chapter 5 considered the market entry of disruptive innovations. In all of the historical cases an innovation replaced a market-leading incumbent. Diffusion models such as Rogers' Theory only consider the market entry of one innovation, and not many at the same time. The situation today in the automotive industry is different where incumbent market leading ICEVs are being displaced by BEVs, PHEVs, HEVs, natural gas and LPG vehicles, biofuel enabled vehicles, and potentially FCVs. Finding historical cases where an incumbent has been displaced by a number of innovations may provide insights for this situation, and help understand what might occur in the coming years of transitioning from ICEVs. It may emerge that it is likely that just one innovation will be established as the market leading automotive technology with the others operating only in niche markets.

Understanding infrastructural development was not the primary aim of this thesis, however it is difficult to consider FCVs without exploring this issue. Chapter 7 did not consider siting of hydrogen stations. Understanding in which regions to site early FCV infrastructure is needed so that they are targeted in regions with the highest number of potential FCV adopters. Lack of infrastructure was a significant barrier to adoption of FCVs and therefore this topic should be investigated further in future studies. These studies should bring together research that aims to map out hydrogen infrastructure and consumer adoption research so that stations can be placed in regions where consumer acceptance is likely. Hopefully the result of this would be increasing market penetration rates of the vehicles.

The sample of 340 adopters in chapter 8 is large enough to yield a 5% margin of error, however a larger sample would further reduce this error. There is also the potential for some sample bias or self-selection bias by respondents. Due to

cognitive bias' such as 'post purchase rationalisation' the perceptions early adopters have of their own vehicles may always contain a bias. Self-selection bias can also occur whereby certain people are more likely to respond to the questionnaire survey, this can further be impacted by the fact that certain people are more likely to be using electric vehicle forums, where the results were gathered. The views expressed by these respondents may be more positive than those of the general populations and perhaps some BEV adopters. A further limitation is that this method will omit any BEV adopters who do use these forums from taking part in the study. In order to address this future studies should contact respondents via other means, for example postal recruitment employed by (Tal et al., 2014) could be used.

Something that emerged in chapter 8 was that all early adopters have high socio-economic statuses. This is related to the purchase prices of the vehicles. Nevertheless, work is needed in order to understand how to get car drivers with lower socio-economic statuses to adopt BEVs, perhaps through supporting the sale of second hand BEVs or through larger subsidies. 200 mile BEVs, that cost a similar amount as low-end BEVs and have many shared attributes, with the obvious exception of range, are approaching market entry. Research is needed in order to understand how consumers will perceive these vehicles. These 200-mile BEVs will have the range of a high-end BEV, but the price and attributes of low-end BEVs. Therefore how will these vehicles be perceived? Will more people adopt these vehicles? And once adoption does occur will the likelihood of discontinuance be reduced?

The data in chapter 9 that explored the premium paid for a BEV did not take into account purchase incentives that are available in some regions. The results in the

chapter are still useful in highlighting differences in what low and high-end adopters have paid, however taking into account any incentives received will make the data more accurate. The chapter also assumed that if adopters had not chosen a BEV they would have purchased an ICEV that was the same as their previous vehicle. This may not have been the case in reality and adopters may have been considering a very different ICEV had they not purchased their BEV. Therefore data is needed in order to understand what vehicle early adopters would have purchased if they hadn't chosen their BEV. What should also be considered in future research is what premium consumers will pay for 200 mile low-end BEVs. Will it be an amount similar to that of low-end BEVs or high-end BEVs?

Chapter 10 presented qualitative evidence from high-end adopters. It is highly likely that the results presented here would be different for low-end adopters. Studying low-end adopters with in-depth interviews may provide some more insights to BEVs. It emerged that the incentives for high-end BEVs are not important for this group of adopters, supporting the suggestion in chapter 9 that this would be the case. With these people being early adopters research should look to understand whether the importance of these incentives might change over time as new groups of adopters, for example the early majority, consider purchasing the vehicles. Will these adopters be more price sensitive and place a higher value on the incentives?

The 11<sup>th</sup> chapter of this thesis investigated high-end BEV adopter attitudes toward FCVs. This resulted in a number of barriers to adoption being identified. It is possible that low-end adopters have different attitudes towards FCVs than high-end adopters. Repeating the study with a sample of low-end adopters may produce different results. Further to studying low-end BEV adopters it may be insightful to investigate

attitudes of adopters of other AFVs, for example adopters of biofuel vehicles or natural gas vehicles. These people in particular have experience owning a vehicle that is fuelled with a fuel using an infrastructure more limited than petroleum refuelling infrastructure. Therefore these consumers may have some insights for FCVs.

The final results chapter in this thesis was the only one that sampled people who have first hand experience on a FCV. This sample was quantitative but the sample size was small. A future study should aim to gather a larger quantitative sample in order to make the results statistically valid. This will also allow the use of more advanced statistical models, for example regression analysis. If a larger quantitative example cannot be gathered, in-depth qualitative interviews with a sample size similar to the one presented in chapter 12 would be appropriate. Chapter 12 briefly explored a sample of 9 early adopters of FCVs in California. This sample is far too small for detailed analysis. Gathering a larger data set, comprising of these consumers, using in-depth interviews may be useful in understanding consumer adoption of FCVs.

All of the studies that gathered qualitative or quantitative data have been unable to explore whether early adopters of BEVs, or whether attitudes towards FCVs, are different in different regions or nations. Are early adopters of BEVs in California the same as early adopters in other states in the USA? Are adopters in the USA different to adopters in Europe for example? This research question could be answered through undertaking qualitative in-depth interviews with early adopters in different regions or countries in order to understand whether their preferences and motivations differ from one region or country to another.

Of all of these areas of future study, FCV consumer adoption research is needed the most, specifically concentrating on infrastructural requirements to convince consumers to adopt. BEV literature has benefitted from research from different authors in different countries all contributing to understanding the issues on hand. FCV adoption literature is far more limited, therefore any future studies should preferably look to investigate the market entry of FCVs by looking into consumer attitudes, and also the development of hydrogen infrastructure. This research will help guide the development of FCVs by OEMs and help develop policies to effectively encourage their adoption by consumers, as has been the case for BEVs.

### **13.5 Summary**

The research conducted in this thesis suggests that FCVs will not be adopted by consumers at present due to them being perceived as having no decisive benefits, or relative advantage, compared to ICEVs or BEVs. This means that consumers will not be drawn away from ICEVs to adopt FCVs. It also means that when consumers are considering a new automotive technology they will preferentially select BEVs over FCVs. It is possible that a small number of consumers will be attracted to FCVs, as they already have been. However, discontinuance is likely to be high amongst the people that do adopt due to the lack of relative advantage. And it currently looks unlikely that FCVs will take any significant market shares in the passenger vehicle market.

It could be possible to improve FCVs so that they have benefits compared to both ICEVs and BEVs by following the recommendations that were made in this final chapter. Prior to doing this though policy makers, OEMs and academics should

consider if FCV passenger cars are really needed within the automotive sector. FCVs and BEVs both work towards reducing carbon emissions, improving urban air pollution and reducing fossil fuel resource depletion. It is probable that concentrating efforts towards the introduction of BEVs will be a more effective strategy opposed to trying to support both FCVs and BEVs. BEVs have decisive benefits compared to ICEVs meaning consumers will be more likely to adopt the vehicles, and this will be especially true when more BEVs are available with ranges of around 200 miles. BEVs have already made significant headway with over 1 million vehicles on the roads globally and there being 550,000 sales in 2015 alone. This gives them a significant first mover advantage, and means that their diffusion into the automotive market is already underway. Concentrating on one automotive innovation will also be more cost effective by only building one infrastructure rather than both BEV recharging networks and hydrogen refuelling stations. It will be more cost effective for OEMs as they only need to invest in one new vehicle type.

For FC stakeholders their efforts should be concentrated towards applications where FCs have tangible benefits compared to both incumbent technologies and competing innovations. This was discussed above and is presented in the publication (Hardman et al., 2015) This will lead to them being adopted by consumers or organisations and may result in returns on the already sizable investments that have been made into FCs.

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# Appendices

## Appendix 1: Online Questionnaire Survey

"Q1","How many cars are there in your household?"

"1","2","3","4","5+"

"Q2","How many people are there in your household?"

"1","2","3","4","5+"

"Q3","How many people in your household hold a full driving license?"

1","2","3","4","5+"

"Q4","The following statements are concerned with your personality and opinions. To what extent do you agree or disagree with these statements. (Check one box for each statement)"

"Q4\_a","You regularly participate in social activity"

"Agree Strongly", "Agree Slightly", "Neither Agree or Disagree", "Disagree Slightly", "Disagree Strongly"

"Q4\_b","You regularly interact with people in your local community"

"Agree Strongly", "Agree Slightly", "Neither Agree or Disagree", "Disagree Slightly", "Disagree Strongly"

"Q4\_c","You are often involved in matters that require you to interact with people outside of your local network"

"Agree Strongly", "Agree Slightly", "Neither Agree or Disagree", "Disagree Slightly", "Disagree Strongly"

"Q4\_d","You have a small network of people you know"

"Agree Strongly", "Agree Slightly", "Neither Agree or Disagree", "Disagree Slightly", "Disagree Strongly"

"Q4\_e","People you know are often influential when you are considering buying or trying a new technology"

"Agree Strongly", "Agree Slightly", "Neither Agree or Disagree", "Disagree Slightly", "Disagree Strongly"

"Q4\_f","You are often good at understanding peoples feelings"

"Agree Strongly", "Agree Slightly", "Neither Agree or Disagree", "Disagree Slightly", "Disagree Strongly"

"Q4\_g", "You are often contemplative when you are making a decision"

"Agree Strongly", "Agree Slightly", "Neither Agree or Disagree", "Disagree Slightly", "Disagree Strongly"

"Q4\_h", "You are often reluctant to change your routine"

"Agree Strongly", "Agree Slightly", "Neither Agree or Disagree", "Disagree Slightly", "Disagree Strongly"

"Q5", "The following statement focus upon how you respond to new technologies. To what extent do you agree or disagree with the following. (Check one box for each statement)"

"Q5\_a", "You want to be among the first people to try a new technology"

"Agree Strongly", "Agree Slightly", "Neither Agree or Disagree", "Disagree Slightly", "Disagree Strongly"

"Q5\_b", "You invest in new technologies soon after they become available for purchase"

"Agree Strongly", "Agree Slightly", "Neither Agree or Disagree", "Disagree Slightly", "Disagree Strongly"

"Q5\_c", "Friends will often use you as a point of reference for new technologies"

"Agree Strongly", "Agree Slightly", "Neither Agree or Disagree", "Disagree Slightly", "Disagree Strongly"

"Q5\_d", "You often take your time before making a decision to invest in a new technology"

"Agree Strongly", "Agree Slightly", "Neither Agree or Disagree", "Disagree Slightly", "Disagree Strongly"

"Q5\_e", "You are often sceptical about new technologies"

"Agree Strongly", "Agree Slightly", "Neither Agree or Disagree", "Disagree Slightly", "Disagree Strongly"

"Q5\_f", "You tend to invest in new technology once you have been convinced about the benefits of using it"

"Agree Strongly", "Agree Slightly", "Neither Agree or Disagree", "Disagree Slightly", "Disagree Strongly"

"Q5\_g", "You rarely invest in new technologies"

"Agree Strongly", "Agree Slightly", "Neither Agree or Disagree", "Disagree Slightly", "Disagree Strongly"

"Q5\_h", "You prefer to stick to existing technologies that you are familiar with"

"Agree Strongly", "Agree Slightly", "Neither Agree or Disagree", "Disagree Slightly", "Disagree Strongly"

"Q5\_i", "You would consider yourself willing to take a risk when it comes to investing in new technologies"

"Agree Strongly", "Agree Slightly", "Neither Agree or Disagree", "Disagree Slightly", "Disagree Strongly"

"Q5\_j", "Uncertainty of the success of a technology in the long-term makes you feel uncomfortable about investing in it"

"Agree Strongly", "Agree Slightly", "Neither Agree or Disagree", "Disagree Slightly", "Disagree Strongly"

"Q6", "Vehicle Number 1"

"Q6\_a", "What is the make?"

"Q6\_b", "What is the model?"

"Q6\_c", "What year was the vehicle purchased?"

"Q6\_d", "Is the car owned, leased or a company car?"

"Q6\_e", "What type of drivetrain does the vehicle have?"

"Petrol", "Hybrid", "Diesel", "Electric", "Other"

"Q7", "Vehicle Number 2"

"1", "Other"

"Q7\_a", "What is the make?"

"Q7\_b", "What is the model?"

"Q7\_c", "What year was the vehicle purchased?"

"Q7\_d", "Is the car owned, leased or a company car?"

"Q7\_e", "What type of drivetrain does the vehicle have?"

"Petrol", "Hybrid", "Diesel", "Electric", "Other"

"Q8", "Vehicle Number 3"

"1", "Other"

"Q8\_a", "What is the make?"

"Q8\_b", "What is the model?"

"Q8\_c", "What year was the vehicle purchased?"

"Q8\_d", "Is the car owned leased or a company car?"

"Q8\_e", "What type of drivetrain does the vehicle have?"

"Q9", "Vehicle Number 4"

"1", "Other"

"Q9\_a", "What is the make?"

"Q9\_b", "What is the model?"

"Q9\_c", "What year was the vehicle purchased?"

"Q9\_d", "Is the car owned, leased or a company car?"

"Q9\_e", "What type of drivetrain does the vehicle have?"

"Petrol", "Hybrid", "Diesel", "Electric", "Other"

"Q10", "Vehicle Number 5"

"Q10\_a", "What is the make?"

"Q10\_b", "What is the model?"

"Q10\_c", "What year was the vehicle purchased?"

"Q10\_d", "Is the car owned, leased or a company car?"

"Q10\_e", "What type of drivetrain does the vehicle have?"

"Petrol", "Hybrid", "Diesel", "Electric", "Other"

"Q11", "When considering a new vehicle purchase, which six of the following are most important and which six are least important? (Check the six most important and the six least important)"

"Q11\_a", "Brand"

""Most Important", "Least Important"

"Q11\_b", "Vehicle Image"

""Most Important", "Least Important"

"Q11\_c", "Vehicle Price"

""Most Important", "Least Important"

"Q11\_d", "Vehicle Range"

""Most Important", "Least Important"

"Q11\_e", "Time to Refuel"

""Most Important", "Least Important"

"Q11\_f", "Performance (speed, acceleration)"

""Most Important", "Least Important"

"Q11\_g", "Fuel Economy"

""Most Important", "Least Important"

"Q11\_h", "Environmental Impacts (CO2 emissions)"

""Most Important", "Least Important"

"Q11\_i", "Life Style Fit"

""Most Important", "Least Important"

"Q11\_j", "Running Costs"

""Most Important", "Least Important"

"Q12", "Are you concerned about the rising cost of fuel?"

"Yes", "No"

"Q13", "Prior to owning a Battery Electric Vehicle had you spoke to other electric vehicle owners about their experiences?"

"Yes", "No"

"Q14", "Prior to owning a Battery Electric Vehicle had you researched information about electric vehicle ownership?"

"Yes", "No"

"Q15", "Prior to owning a Battery Electric Vehicle had you been in an electric vehicle?"

"Yes", "No"

"Q16", "Prior to owning your current Battery Electric Vehicle had you owned any of the following?"

"Hybrid", "Electric", "Biofuel", "None", "Other"

"Q17", "What was your primary vehicle before owning a Battery Electric Vehicle? (list make and model)"

"Q18", "The following questions relate to owning a Battery Electric Vehicle. To what extent do you agree or disagree with the following statements?"

"Q18\_a", "Owning a Battery Electric Vehicle has meant you have had to make lifestyle changes"

"Agree Strongly", "Agree Slightly", "Neither Agree or Disagree", "Disagree Slightly", "Disagree Strongly"

"Q18\_b", "A Battery Electric Vehicle is only suitable as an additional vehicle (i.e. extra vehicles are required in the household)"

"Agree Strongly", "Agree Slightly", "Neither Agree or Disagree", "Disagree Slightly", "Disagree Strongly"

"Q19", "Please use the space below to list any advantages you think you (or your household) has experienced by using an electric vehicle?"

"Q20", "Please use the space below to outline in your own words why you purchased a Battery Electric Vehicle."

"Q21", "How easy do you think the following activities are for your Battery Electric Vehicle compared to a traditional petrol car?"

"Q21\_a", "Driving"

"Very Easy", "Somewhat Easy", "Similar", "Somewhat Difficult", "Very Difficult"

"Q21\_b", "Recharging/ Refuelling"

"Very Easy", "Somewhat Easy", "Similar", "Somewhat Difficult", "Very Difficult"

"Q22", "In order to understand how a Battery Electric Vehicle suits your lifestyle, please answer the following questions"

"Q22\_a", "How often do you use your Battery Electric Vehicle?"

"Daily", "Weekly", "Every 2 Weeks", "Monthly", "Every 2 Months", "Every 6 Months", "Yearly", "Never"

"Q22\_b", "How often does your driving distance exceed 100 miles in one day"

"Daily", "Weekly", "Every 2 Weeks", "Monthly", "Every 2 Months", "Every 6 Months", "Yearly", "Never"

"Q22\_c", "How often do you spend an overnight stay away from home (where you might not be able to recharge your vehicle)?"

"Daily", "Weekly", "Every 2 Weeks", "Monthly", "Every 2 Months", "Every 6 Months", "Yearly", "Never"

"Q22\_d", "If there is an additional vehicle in your household how often it is used for trips not possible in a Battery Electric Vehicle?"

"Daily", "Weekly", "Every 2 Weeks", "Monthly", "Every 2 Months", "Every 6 Months", "Yearly", "Never"

"Q23", "Considering each of the following vehicle attributes how do you believe your Battery Electric Vehicle (BEV) compares to a petrol powered car?"

"Q23\_a","Brand"

"BEV is far superior", "BEV is slightly superior", "BEV is similar", "BEV is slightly worse", "BEV is far worse"

"Q23\_b","Vehicle Image/Looks"

"BEV is far superior", "BEV is slightly superior", "BEV is similar", "BEV is slightly worse", "BEV is far worse"

"Q23\_c","Purchase Price"

"BEV is far superior", "BEV is slightly superior", "BEV is similar", "BEV is slightly worse", "BEV is far worse"

"Q23\_d","Vehicle Range"

"BEV is far superior", "BEV is slightly superior", "BEV is similar", "BEV is slightly worse", "BEV is far worse"

"Q23\_e","Time to Refuel"

"BEV is far superior", "BEV is slightly superior", "BEV is similar", "BEV is slightly worse", "BEV is far worse"

"Q23\_f","Vehicle Performance (speed, acceleration)"

"BEV is far superior", "BEV is slightly superior", "BEV is similar", "BEV is slightly worse", "BEV is far worse"

"Q23\_g","Fuel Economy"

"BEV is far superior", "BEV is slightly superior", "BEV is similar", "BEV is slightly worse", "BEV is far worse"

"Q23\_h","Environmental Impact (CO2 emissions, etc.)"

"BEV is far superior", "BEV is slightly superior", "BEV is similar", "BEV is slightly worse", "BEV is far worse"

"Q23\_i","Life Style Fit"

"BEV is far superior", "BEV is slightly superior", "BEV is similar", "BEV is slightly worse", "BEV is far worse"

"Q23\_j","Running Costs"

"BEV is far superior", "BEV is slightly superior", "BEV is similar", "BEV is slightly worse", "BEV is far worse"

"Q24","To what extent do you agree or disagree with the following statements?"

"Q24\_a","You keep up to date with what is happening in the media"

"BEV is far superior", "BEV is slightly superior", "BEV is similar", "BEV is slightly worse", "BEV is far worse"

"Q24\_b", "You often listen to the views of experts on matters that are important to you"

"BEV is far superior", "BEV is slightly superior", "BEV is similar", "BEV is slightly worse", "BEV is far worse"

"Q24\_c", "The media has influenced your attitude towards fully electric vehicles"

"BEV is far superior", "BEV is slightly superior", "BEV is similar", "BEV is slightly worse", "BEV is far worse"

"Q24\_d", "Your family or friends have influenced your views in electric vehicles"

"BEV is far superior", "BEV is slightly superior", "BEV is similar", "BEV is slightly worse", "BEV is far worse"

"Q24\_e", "Fully electric vehicles mostly receive positive coverage in the media"

"BEV is far superior", "BEV is slightly superior", "BEV is similar", "BEV is slightly worse", "BEV is far worse"

"Q25", "When is your households next vehicle purchase or lease likely to be?"

"<1 Year", "1-2 Years", "2-3 Years", "4+ Years"

"Q26", "Will the car be new or second hand?"

"New", "Second Hand", "Other"

"Q27", "Will your next car be another vehicle of the same brand as your current BEV?"

"Yes", "No", "Don't Know"

"Q28", "Will the car be another battery electric vehicle?"

"Definitely Not", "Probably Not", "Unsure", "Probably Yes", "Definitely Yes"

"Q29", "Will the vehicle be purchase, leased or a company car?"

"Q30", "How did you originally find out about the Battery Electric Vehicle you own?"

"Auto Magazine", "Newspaper Article", "Radio News", "TV News", "Social Media (Facebook, Twitter etc.)", "TV Program (Not News)", "Word of Mouth", "TV Advert", "Other"

"Q31", "Other than the Battery Electric Vehicle you own would you consider owning any other fully electric vehicles?"

"Yes", "No"



"Q31\_a","If NO please state why (e.g range issues, quality issues, cost issues, etc.)"

"Q32","What is your current employment status?"

"Working Full Time (30+hours)", "Working Part Time (Less than 30 hours)",  
"Voluntary Worker", "Unemployed- Seeking Work", "Unemployed- Not Seeking  
Work", "Retired", "In Education", "Other"

"Q33","Which income band most accurately represents your house hold income?"

"<\$10,000", "\$10,001-40,000", "\$40,001-90,000", "\$90,001-180,000", "\$180,001-  
400,000", "\$400,000+", "Prefer not to say"

"Q34","What is your gender?"

"Male", "Female"

"Q35","What is your age?"

"17-24", "25-34", "35-44", "45-54", "55-64", "65-74", "75-84", "85+"

"Q36","Please indicate the highest formal qualification you have received"

"A Doctorate or equivalent", "Masters Degree or equivalent", "Bachelors Degree or  
equivalent", "High School Diploma or equivalent", "Other"

"Q37","Which of the following best describes your current occupation (or previous  
occupation if retired)?"

"Higher managerial, higher administrative or higher professional"

"Intermediate managerial, intermediate administrative or intermediate professional"

"Supervisors, clerical and junior managerial, junior administrative or junior  
professional"

"Skilled manual worker"

"Semi and unskilled manual worker"

"Casual work of unemployed"

"Other"

"Q38","Where do you currently live? (If you live in the USA or Canada please choose  
State or Province, US states are at the top of the list, Canadian Provinces are at the  
bottom. If you live outside of the USA or Canada please choose the continent e.g  
Europe)"

"Q39","Name"

"Q40","E-mail address"

"Q41", "Would you like to be contacted about this research in the future? This may include being requested to take part in future electric vehicle studies"

"Yes I would like to be contacted", "No do not contact me"

## Appendix 2: Verbally Administered Questionnaire Survey

The first questions ask about your opinions of the fuel cell vehicle you have just been in along with questions about electric vehicles.

1. Considering each of the following vehicle attributes how do you believe a FCV compares to a petrol powered car?

	Far Worse			Slightly Worse			Similar			Slightly Superior			Far Superior		
Brand															
Image/Looks															
Purchase Price															
Vehicle Range															
Time to Refuel															
Performance															
Fuel Economy															
Environ. Impacts															
Life Style Fit															
Running Costs															
Safety															
Technology															

2. Considering each of the following vehicle attributes how do you believe a FCV compares to a battery electric car?

	Far Worse			Slightly Worse			Similar			Slightly Superior			Far Superior		
Brand															
Image/Looks															
Purchase Price															
Vehicle Range															
Time to Refuel															
Performance															
Fuel Economy															
Environ. Impacts															
Life Style Fit															
Running Costs															
Safety															
Technology															

3. What did you like about the fuel cell vehicle, what didn't you like?

4. Would you consider a fuel cell vehicle for your next car?

Reasons for answer

The next questions relate to your background, firstly asking what cars you currently have in your household, and then asking some socio-economic questions. These questions help researchers understand any relationships between people's backgrounds and their opinions of alternative fuel vehicles.

5. How cars do you have in your household?

1	2	3	4	5+

Vehicle 1

Make	
Model	
Year	
Vehicle Type	
Owned, Lease, Company Car?	

Vehicle 2

Make	
Model	
Year	
Vehicle Type	
Owned, Lease, Company Car?	

### Vehicle 3

Make	
Model	
Year	
Vehicle Type	
Owned, Lease, Company Car?	

### Vehicle 4

Make	
Model	
Year	
Vehicle Type	
Owned, Lease, Company Car?	

### Vehicle 5

Make	
Model	
Year	
Vehicle Type	
Owned, Lease, Company Car?	

### 6. What is your age?

Prefer not to answer	
17-24	
25-34	
35-44	
45-54	
55-64	
65-74	
75-85	
85+	

7. What is your household income?

Prefer not to answer	
<£10,000	
£10,001-20,000	
£20,001-30,000	
£30,001-40,000	
£40,001-50,000	
£50,001-60,000	
£60,001-70,000	
£70,001-80,000	
£80,001-90,000	
£90,001-100,000	
>£100,001	

8. What is the highest level of formal education that you have achieved?

Prefer not to answer	
GCSE or Equivalent	
A Level or Equivalent	
Undergraduate Degree or Equivalent	
Masters Degree or Equivalent	
Doctorate or Equivalent	
Other	

9. How many people are there in your household?

1	
2	
3	
4	
5	
6+	
Prefer not to answer	

Name	
Email Address	
Would you like to be contacted for future studies?	

### **Appendix 3: California Tesla Interview Topics**

- Number of household vehicles, household vehicles, highest level of education, profession, age, gender, etc.
- How they found out about Tesla?
- Why they bought a Tesla?
- The benefits of owning a Tesla?
- Anything they would like their Tesla to do that it cant?
- Would they have purchased their Tesla without the state and federal incentive?
- Would they go back to ICEV ownership?
- Would they adopt FCV?